ENERGY EFFICIENCY IN U.K. SHOPPING CENTRES

by

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ABSTRACT

Energy efficiency in shopping centres means providing comfortable internal environment and services to the occupants with minimum energy use in a cost-effective and environmentally sensitive manner.

This research considers the interaction of three factors affecting the energy efficiency of shopping centres: i) performance of the building fabric and services; ii) management of the building in terms of operation, control, maintenance and replacement of the building fabric and services, and company's energy policy; iii) occupants' expectation for comfort and awareness of energy efficiency.

The aim of the investigation is to determine the role of the above factors in the energy consumption and carbon emissions of shopping centres and the scope for reducing this energy usage by changing one or all the three factors. The study also attempts to prioritize the changes in the above factors that are more cost-effective at reducing that energy consumption and identify the benefits and main economic and legal drivers for energy efficiency in shopping centres.

To achieve these targets, three case studies have been analysed.

Using energy data from bills, the performance of the selected case studies has been assessed to establish trends and current energy consumption and carbon emissions of shopping centres and their related causes.

A regression analysis has attempted to break down the energy consumption of the landlords' area by end-use to identify the main sources of energy usage and consequently introduce cost-effective measures for saving energy.

A monitoring and occupants' survey in both landlords' and tenants' areas have been carried out at the same time to compare the objective data of the environmental conditions with the subjective impressions of shoppers and shopkeepers. In particular, the monitoring aimed at assessing the internal environment to identify possible causes of discomfort and opportunities for introducing energy saving measures. The survey looked at determining the occupants' expectation for comfort and awareness of energy efficiency in shopping centres.

The results show the complexity of prioritizing the three factors affecting energy efficiency in shopping centres, highlighting the relationships between those factors, and the role of different actors, involved in the life of shopping centres, in the energy and environmental performance of these buildings.

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Chapter 1:

INTRODUCTION

1.1. Purpose of energy efficiency in the U.K.

The object of this dissertation is energy efficiency in U.K. shopping centres.

Based on CIBSE Guide F[1], buildings consume nearly half the energy used in the U.K. Tangible benefits from energy efficiency ranging from the individual to the national level are:

- improved design and operation of buildings;
- better working environments;
- life-cycle cost savings;
- improved environmental and public health conditions: mainly through reduced emissions of carbon dioxide (CO_2) (most significant contributor to global warming) and SO_x and NO_x (contributors to acid rain), and reduced consumption of finite fossil fuels[2,3];
- added market value of buildings, when energy efficiency is perceived as a significant benefit by developers and letting agents[4].

1.2. The U.K. energy use in retail buildings

According to BR 366[5], the use of energy in retail buildings has an important business and environmental dimension. By reducing energy consumption, significant reductions can be made to both the cost of energy to the business, and the amount of CO_2 emitted to the atmosphere.

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[1] *Energy efficiency in buildings*. CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Pages 1-1 – 1-4.
[2] *Climate Change 2001*. Intergovernmental Panel on Climate change. Geneva. July 2001.
[3] *Energy – the changing climate*. Twenty Second Report of the Royal Commission on Environmental Pollution. Royal Commission on Environmental Pollution. London. June 2000.
[4] *Energy efficiency in buildings*. CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 1-1.

In this connection, Figures 1.1 and 1.2 show that in 2000 commercial and public sector buildings counted for 28 % of the total energy consumption of the U.K. by building type and the retail sector had the highest national energy consumption by end-use in non-domestic buildings (19 %).

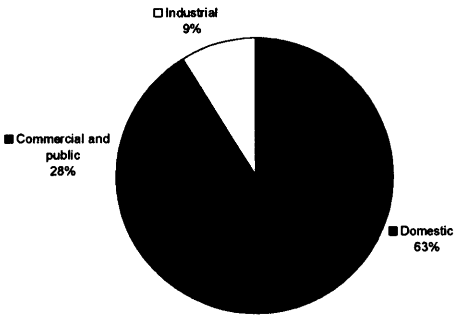

Figure 1.1. Total U.K. delivered energy consumption by building type in 2000. (Source: CIBSE Guide F[6])

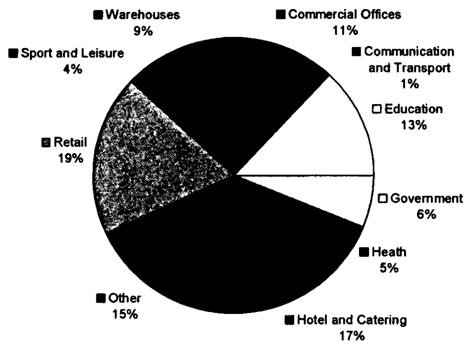

Figure 1.2. Total U.K. delivered energy consumption by end-use in 2000. (*Source*: BR 442[7])

The annual energy bill for all U.K. retail outlets is £ 1.8 billion. Some 5-10 % of this (£ 90-180 million) could be saved through good design and low-cost good housekeeping measures alone. The energy costs may represent only a small fraction of retailers' turnover, but they constitute a much more significant fraction of their profits[8].

Almost half of the total CO_2 emissions in the U.K. are associated with the energy used in buildings. The CO_2 emissions due to energy use within a retail building arise from:

- space heating requirements, the heating system, controls and fuel used;
- water heating requirements, water heating system, controls and fuel used;
- air-conditioning systems;
- food refrigeration;
- cooking energy and fuel used;
- energy used for lights and appliances.

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[5] Prior J. J. *Sustainable retail premises: an environmental guide to design, refurbishment and management of retail premises.* BRE Report (BR 366). Building Research Establishment (BRE). London. 1999. Pages 12-13.
[6] *Energy efficiency in buildings.* CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 1-2.
[7] Pout C. H., MacKenzie F., Bettle R. *Carbon dioxide emissions from non-domestic buildings: 2000 and beyond.* BRE Report 442 (BR 442). Building Research Establishment (BRE). London. 2002. Page 13.
[8] Cook M. G. *Checkout retail savings.* Energy Management Journal. May/June 1996.

CO_2 production is therefore related to the amount and type of fuel consumed[9].

The optimum choice of fuel depends on the size and location of the retail premises. Generally, retail premises with low CO_2 production will have high insulation standards, no air-conditioning, good use of daylighting, energy efficient electric lighting with effective controls, efficient appliances and gas as the predominant fuel[10].

1.3. Research object

In the light of the previous overview, the retail sector has an important role in the energy consumption and carbon emissions of the U.K.

The market of shopping centres also plays a significant part in the national economy.

In fact, the retail floor space has grown faster than the economy as a whole over the last 15 years. This pattern is expected to continue in the future[11,12,13]. The current trend of development is toward large shopping centres, as either new or extensions of existing ones[14].

Therefore, building and managing energy efficient shopping centres have a deep impact on both the economy and the environment.

Nevertheless, little information has been found on this topic in literature.

On the basis of personal studies and researches, *energy efficiency in shopping centres* means providing comfortable internal environment and services to the occupants with minimum energy use in a cost-effective and environmentally sensitive manner.

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[9] Prior J. J. *Sustainable retail premises: an environmental guide to design, refurbishment and management of retail premises.* BRE Report (BR 366). Building Research Establishment (BRE). London. 1999. Page 12.

[10] Prior J. J. *Sustainable retail premises: an environmental guide to design, refurbishment and management of retail premises.* BRE Report (BR 366). Building Research Establishment (BRE). London. 1999. Page 12.

[11] Bach M. and Thurstain-Goodwin M. of Geofutures. *The Future of Retail Property. In-town or out-of-town?*. Research project carried out by the British Council of Shopping Centres (BCSC). http://www.bcsc.org.uk/research/FORP/project06.htm, accessed August 2006.

[12] Blake N., Morley S., Bach M. *The Future of Retail Property. How much space can the market absorb?*. Research project carried out by the British Council of Shopping Centres (BCSC). http://www.bcsc.org.uk/research/FORP/project05.htm, accessed August 2006.

[13] Centre Retailing 2006. Estates Gazette. London. Page 87.

[14] *A Briefing Guide for Shopping Centre Development.* British Council of Shopping Centres (BCSC). London. 2000. Page 43.

Therefore, the energy efficiency of a shopping centre is affected by the interaction of three factors:

- the performance of the building fabric and services;
- the management of the building in terms of operation, control, maintenance and replacement of the building fabric and services, and company's energy policy;
- the occupants' expectation for comfort and awareness of energy efficiency.

In relation to these elements, the project aims at answering two main questions:

1) Which is the role of the above factors in the energy consumption and related carbon emissions of shopping centres?
2) Which is the scope for reducing the energy consumption and related carbon emissions of shopping centres by changing one or all the three factors?

In addition, the project will attempt to prioritize the changes that are more cost-effective at reducing energy consumption and related carbon emissions of this type of building.

Before answering these questions, the next chapter will try to determine the main economic and legal drivers of energy efficiency for improving energy and environmental performance of shopping centres. Besides, the same chapter will also introduce the current methodology of benchmarking, which is useful to assess the energy and carbon emissions performance of shopping centres, as well as target and prioritize possible improvements in their energy efficiency.

Finally, some background information will be covered in the following chapter to clarify the object of this study, in terms of definition of shopping centre, its building typology and development criterion, and operation of shopping centres.

Chapter 2:

BACKGROUND INFORMATION ON SHOPPING CENTRES AND RELATED ENERGY EFFICIENCY

2.1. Definition of shopping centre, its building typology and development criterion

According to Encyclopædia Britannica[15], a *shopping centre*, also called *shopping mall*, or *shopping plaza*, is a 20th-century adaptation of the historical marketplace, with accommodation made for automobiles. A shopping centre is a collection of independent retail stores, services and a parking area conceived, constructed and maintained by a management firm as a unit. Shopping centres may also contain restaurants, banks, theatres, professional offices, services stations and other establishments. All the stores and facilities, contained in a building or set of buildings, are connected by walkways that may or may not be enclosed[16].

A shopping centre must meet the needs of its developer/owner, its tenants and its customers. These three parties form the "golden triangle", the satisfaction of each providing the basis of satisfaction for the others (see Figure 2.1). Their needs are of equal importance and must be met to create success[17].

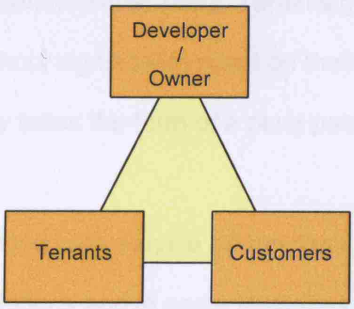

Figure 2.1. Golden Triangle.

[15] "shopping centre". Encyclopædia Britannica Online 2006. http://search.eb.com/eb/article-9067491, accessed 30 May 2006
[16] "shopping mall". Wikipedia. http://en.wikipedia.org/wiki/Shopping_centre, accessed August 2006.
[17] *A Briefing Guide for Shopping Centre Development*. British Council of Shopping Centres (BCSC). London. 2000. Page 2.

2.2. Operation of shopping centres

Operational efficiency in shopping centres provides savings which reflect in service charges[18].

A large proportion of operational cost is given by the provision of building services.

The services fall into two categories:

- *tenants services*, which are those provided into tenant demised areas for connection and ongoing distribution by individual tenants;
- *landlords services*, which are those fully installed for operation by centre management[19].

Standard shop units are generally provided with water, electricity, drainage, telecoms and (in covered shopping centres) a sprinkler main connection with an isolating valve.

The services are terminated within the tenant demise, usually at the rear of the unit and the tenant then has responsibility to arrange connection, metering and ongoing service installation within the unit.

A gas service is not normally provided to standard units unless they are to be occupied for catering use or a specific provision has been incorporated in the agreement of lease.

Other services that may be provided are interface connections with the landlord fire and security alarm systems, and connections to communal satellite communications dishes.

In some centres a communal condenser plant system may be installed by the landlord with a condenser water system providing connections to tenant air-conditioning systems. Since the capital cost of the communal plant is borne by the landlord and the operational cost is added to the service charge this is not the preferred solution for either party. Tenants generally prefer to install and operate their own plant, if this is possible without significant impact on their own, or adjoining, demised areas.

In standard units tenant plant usually takes the form of a plant package installed at roof level or at high level on an external wall.

Large store units are similarly provided with service connections into their demised area and a gas service is included. Dedicated sub-stations and in some instances, sprinkler tanks, may be required[20].

[18] *A Briefing Guide for Shopping Centre Development.* British Council of Shopping Centres (BCSC). London. 2000. Page 3.
[19] *A Briefing Guide for Shopping Centre Development.* British Council of Shopping Centres (BCSC). London. 2000. Page 13.
[20] *A Briefing Guide for Shopping Centre Development.* British Council of Shopping Centres (BCSC). London. 2000. Page 13.

The landlord is responsible for providing service supplies to tenancies as described above, together with all associated sub-stations, switch-rooms, sprinkler tanks, pump systems and stand by generation.

Additionally mains supplies serve the landlords installations in malls, service areas, and management and customer care facilities.

Such supplies are separately metered so that their operating costs can be calculated and apportioned in the service charge to tenants[21].

2.3. Service charge

In shopping centres there are always common areas shared between several tenants. These areas include staircases, service yards, storage areas, plant rooms, locations of centre management staff, escalators and lifts. All of these are normally maintained by the landlord and paid for by the tenants through a service charge[22].

The *service charge* levied by the landlord of a shopping centre on its tenants covers the cost of maintaining, lighting, heating and/or cooling, and cleaning all the common parts of the centre. This includes lifts and escalators and provision of centre management staff and their accommodation[23].

The service charges are usually based on the net area occupied by the tenant as a fraction of the total area occupied by all the tenants. Where an individual tenant does not have access to all the services available to some of the others, this should be reflected in an adjustment of their service charge. A well run system allows tenants to receive detailed breakdowns of the costs of maintaining the common parts of a shopping centre[24].

[21] *A Briefing Guide for Shopping Centre Development.* British Council of Shopping Centres (BCSC). London. 2000. Pages 13-14.

[22] Prior J. J. *Sustainable retail premises: an environmental guide to design, refurbishment and management of retail premises.* BRE Report (BR 366). Building Research Establishment (BRE). London. 1999. Page 47.

[23] Prior J. J. *Sustainable retail premises: an environmental guide to design, refurbishment and management of retail premises.* BRE Report (BR 366). Building Research Establishment (BRE). London. 1999. Page 48.

[24] Prior J. J. *Sustainable retail premises: an environmental guide to design, refurbishment and management of retail premises.* BRE Report (BR 366). Building Research Establishment (BRE). London. 1999. Page 48.

As Figure 2.2 illustrates, energy probably represents between 10 % and 25 % of the cost of running a shopping centre[25].

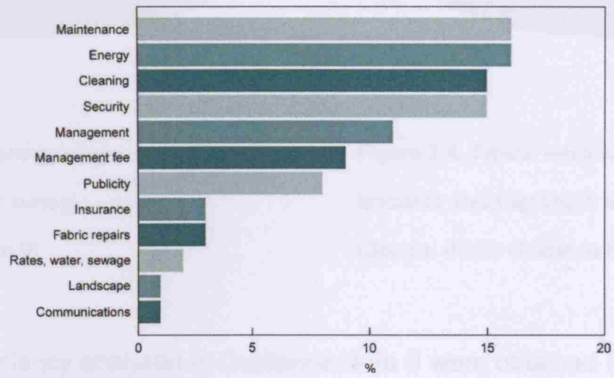

Figure 2.2. Typical allocation of service charge for an enclosed shopping centre: new construction.

(*Source*: British Council of Shopping Centres[26])

The current trend in U.K. shopping centres is for them to be enclosed; indeed refurbishment of older, open centres frequently includes enclosure as part of the process. The benefit of enclosure is primarily the creation of a secure, climate controlled, high quality shopping environment which is attractive to both customers and good quality retailers. However, management and operational costs are also likely to be higher and these will be reflected in higher service charges[27].

The BCSC Guidance Note 9[28] gives an analysis of typical electrical energy use within shopping centres and identifies lighting as the most significant element in the energy component of the service charge. Figure 2.3 shows how the electricity consumption is spread over different end-uses and Figure 2.4 illustrates how the electricity consumption for lighting is spread over different areas.

[25] *Energy efficiency for shopping centres.* Good Practice Guide 134 (GPG 134). Energy Efficiency Best Practice Programme (EEBPP). Department of the Environment, Transport and the Regions (DETR). Building Research Energy Conservation Support Unit (BRECSU). Garston. September 1997. Page 12.
[26] Prior J. J. *Sustainable retail premises: an environmental guide to design, refurbishment and management of retail premises.* BRE Report (BR 366). Building Research Establishment (BRE). London. 1999. Page 48.
[27] *A Briefing Guide for Shopping Centre Development.* British Council of Shopping Centres (BCSC). London. 2000. Page 5.
[28] *Energy Efficiency in Shopping Centres.* Guidance Note 9. British Council of Shopping Centres (BCSC). London. October 1992.

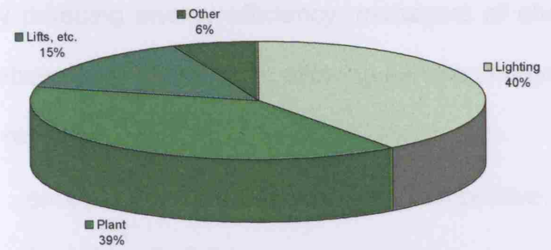

Figure 2.3. Typical electrical energy usage within shopping centres (1992 survey). (*Source*: BCSC Guidance Note 9)

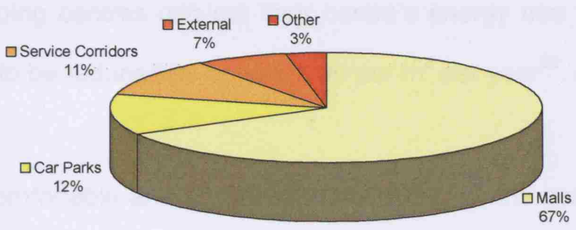

Figure 2.4. Typical electrical energy usage for public and landlords areas lighting in shopping centres (1992 Survey). (*Source*: BCSC Guidance Note 9)

The data on energy efficiency analysed in Guidance Note 9 were obtained from a diverse group of 18 shopping centres in the U.K. They provide a fair interpretation of centres built or refurbished between 1986 and 1992.

The data collected were compared with a recently completed centre at that time, which had the benefit of a critical examination into its electrical energy usage.
This comparison indicated that the percentages deduced from the analysis were compatible with a well-managed and efficient centre.

Nowadays, these figures are quite outdated. However, no recent studies have been found showing a more update energy breakdown by end-use.

2.4. Benefits from energy efficiency in shopping centres

Shopping centres pay, on average, £ 13 per m^2 per year for the energy they use in common areas. In many centres that is more than 10 % of the service charge[29].

[29] *Energy efficiency for shopping centres*. Good Practice Guide 134 (GPG 134). Energy Efficiency Best Practice Programme (EEBPP). Department of the Environment, Transport and the Regions (DETR). Building Research Energy Conservation Support Unit (BRECSU). Garston. September 1997. Page 4.

By pursuing energy efficiency, managers of shopping centres can cut their centre's energy use by between 10 % and 20 %, allowing service charges to be reduced by up to £ 2.60 per m^2 per year[30]. As a result:

- shopping centres become more competitive, comfortable and attractive to shoppers, as the costs for void units fall;
- shopping centres become more attractive to tenants, as the costs of occupation are lower;
- shopping centres have a scope for increasing rents, as reducing energy consumption reduces the total cost of locations;
- shopping centres improve their images by helping the environment, as reducing energy consumption reduces the emissions of gases.

All these benefits add up to higher profits for shopping centres[31].

According to GPG 190[32] in regard to improved customer comfort and working conditions for staff, comfortable temperatures and lighting that enhance the appearance of merchandise are likely to generate higher sales and greater customer loyalty; and a well lit and comfortable working environment for staff will help to show the shopping centre's commitment to their welfare as well as maintaining their productivity.

2.5. Opportunities to save energy in shopping centres

The energy used by a building is profoundly influenced by the management and operation of the building services. Energy management is an essential part of an organisation's environmental policy[33].

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[30] *Energy efficiency for shopping centres*. Good Practice Guide 134 (GPG 134). Energy Efficiency Best Practice Programme (EEBPP). Department of the Environment, Transport and the Regions (DETR). Building Research Energy Conservation Support Unit (BRECSU). Garston. September 1997. Page 4.

[31] *Energy efficiency for shopping centres*. Good Practice Guide 134 (GPG 134). Energy Efficiency Best Practice Programme (EEBPP). Department of the Environment, Transport and the Regions (DETR). Building Research Energy Conservation Support Unit (BRECSU). Garston. September 1997. Page 12.

[32] *Energy efficiency action pack – for retail premises*. Good Practice Guide 190 (GPG 190). Energy Efficiency Best Practice Programme. Department of the Environment (DOE). Building Research Energy Conservation Support Unit (BRECSU). Garston. June 1996. Page 3.

[33] *Energy audits and surveys*. CIBSE Applications Manual AM 5:1991. Chartered Institution of Building Services Engineers (CIBSE). London. 1991. Page 28-29.

Effective maintenance and operation of the building services can have a significant effect on energy efficiency. It will also help to prevent unexpected breakdowns and prolong the life of equipment, avoiding unnecessary use of resources in premature replacement[34].

There are many simple no-cost and low-cost ways to reduce energy consumption in shopping centres by 10 % at least. Many energy efficiency measures will pay for themselves in less than two years[35].

There are four main opportunities to save energy in shopping centres:

- *switching off.* All energy consuming equipment should be switched off when not required. This can be done by the shopping centre's staff, by timer switches, or by adjusting building control systems, and does not cost any money;
- *maintenance.* A number of energy efficiency measures can be carried out as part of the managers' routine maintenance procedures. They should cost little or no more than normal maintenance;
- *refurbishment.* If a shopping centre is due for major refurbishment, it has an ideal opportunity to reduce energy consumption. Energy saving measures taken at this time can be extremely cost-effective;
- *centralised services.* If a shopping centre has centralised services providing heating and/or cooling to tenants, there are opportunities for savings[36].

The action checklist, published in GPG 134[37], shows ways to achieve immediate savings in shopping centres without incurring major costs (see Appendix A.1). Most of the measures will, in fact, cost nothing. Some of them will cut the maintenance costs as well.

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[34] Prior J. J. *Sustainable retail premises: an environmental guide to design, refurbishment and management of retail premises.* BRE Report (BR 366). Building Research Establishment (BRE). London. 1999. Page 52.
[35] *Energy efficiency for shopping centres.* Good Practice Guide 134 (GPG 134). Energy Efficiency Best Practice Programme (EEBPP). Department of the Environment, Transport and the Regions (DETR). Building Research Energy Conservation Support Unit (BRECSU). Garston. September 1997. Page 12.
[36] *Energy efficiency for shopping centres.* Good Practice Guide 134 (GPG 134). Energy Efficiency Best Practice Programme (EEBPP). Department of the Environment, Transport and the Regions (DETR). Building Research Energy Conservation Support Unit (BRECSU). Garston. September 1997. Page 4.
[37] *Energy efficiency for shopping centres.* Good Practice Guide 134 (GPG 134). Energy Efficiency Best Practice Programme (EEBPP). Department of the Environment, Transport and the Regions (DETR). Building Research Energy Conservation Support Unit (BRECSU). Garston. September 1997. Pages 4-5.

2.6. Energy efficiency drivers in shopping centres

According to BCSC Guidance Note No. 46[38], retail business is facing pressure to manage its environmental impact from a wide range of sources, including investors, lobby groups and the general public. Increasingly though this pressure is being translated into legislation and regulations that set minimum standards of performance, this continual and increasingly rapid change in the regulatory framework is adding to business risk. In essence environmental probity is no longer an option but an integral part of retail business.

Various drivers for change can be highlighted.

Under the Kyoto Protocol, the U.K. government is committed to reducing the emission of CO_2 to 12.5 % below 1990 levels by the year 2010, and has set a more stringent internal target to reduce it by 20 % by 2010[39].

U.K. government's long term policy is to reduce carbon emissions by 60 % by 2050, as declared in an energy "white paper"[40].

The government has therefore published a strategy to achieve these reductions[41] covering a wide range of policies, some of which have a direct impact on the buildings industry:

- *taxation*: the Climate Change Levy, which is an additional cost on top of the previous price of energy, affects almost all non-domestic buildings;
- *financial support*: enhanced capital allowances (ECAs) provide a tax incentive to encourage the purchase of energy efficient technologies as defined on the energy efficiency technology list[42];
- *regulation*: the Building Regulations Part L2 (2006)[43] for England and Wales, and its equivalents for Scotland[44] and Northern Ireland[45], imposes new and upgraded requirements aimed at improving the energy efficiency of non-domestic buildings.

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[38] Bateson A. *Sustainability for the retail sector.* Guidance Note No. 46. British Council of Shopping Centres (BCSC). London. November 2005.

[39] *Energy efficiency in buildings.* CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 1-2.

[40] *Our energy future – creating a new carbon economy.* CM5761. The Stationery Office. London. 2003.

[41] *Climate Change – The UK programme.* The Stationery Office. London 2000.

[42] Enhanced Capital Allowances. http://www.eca.gov.uk/, accessed August 2006.

[43] *Conservation of fuel and power in buildings other than dwellings.* The Building Regulations 2000. Approved Document L2. The Stationery Office. London. 2006.

In particular, the Building Regulations Part L (2006 edition)[46] contains the final implementation of the European Directive on the Energy Performance of Buildings[47].

A CIBSE Briefing summarises the requirements of this directive[48].

Besides this, there is an increasing level of legislation addressing energy and environmental issues.

Statutory Instrument 1980 No. 1013: *Control of Fuel and Electricity*[49] specifies a maximum heating level of 19 °C in all non-domestic buildings.

Although not statutory, BS 8207: *Code of practice for energy efficiency in buildings*[50] makes recommendations for achieving energy efficient performance in buildings. It considers both design and operation and provides a framework which can be applied to new designs or to refurbishment.

BS EN ISO 14001: *Environmental management systems*[51] (EMSs) encourages energy efficiency, as it requires monitoring of any significant environmental impact and a commitment to its reduction. Energy is normally the most significant factor in EMSs in buildings.

In addition, there is the Corporate Social Responsibility (CSR), which is about exceeding minimum standards of corporate behaviour.

A part of CSR commitment is environmental responsibility. This is regularly manifested as a statement to reduce energy use of property portfolios or the setting of specific environmental/social benchmarks[52].

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[44] *Technical standards for compliance with the Building Standards (Scotland) Regulations 1990 (as amended).* The Stationery Office. London. 2001.

[45] *Conservation of fuel and power.* The Building Regulations (Northern Ireland) 1994 Technical Booklet F. The Stationery Office. London. 1999.

[46] *Conservation of fuel and power.* The Building Regulations 2000. Approved Document L1/L2. The Stationery Office. London. 2006.

[47] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings *Official J. of the European Communities* 4.1.2003 L1/60. Commission of the European Communities. Brussels. 2001.

[48] *The Energy Performance of Buildings Directive.* CIBSE Briefing 6. Chartered Institution of Building Services Engineers (CIBSE). London. 2003.

[49] *Control of Fuel and Electricity.* The Fuel and Electricity (Heating) (Control) (Amendment) Order 1984 Statutory Instrument 1980 No. 1013. The Stationery Office. London.

[50] *Code of practice for energy efficiency in buildings.* BS 8207:1985. British Standard Institution (BSI). London. 1985.

[51] *Environmental management systems. Specification with guidance for use.* BS EN ISO 14001:1996. British Standard Institution (BSI). London. 1996.

[52] Bateson A. *Sustainability for the retail sector.* Guidance Note No. 46. British Council of Shopping Centres (BCSC). London. November 2005. Page 2.

2.7. Benchmarking for shopping centres

At preset national benchmarks for shopping centres are not available, but in the U.K. there are two methodologies of benchmarking, suitable for this type of buildings:

- the Building Research Establishment Environmental Assessment Method (BREEAM) for Retail[53], which is a non-statutory means of judging buildings against environmental targets and standards (for further details see Appendix A.2);
- the Upstream environmental benchmarking for shopping centres[54], which is a private means to assess current performance of buildings and prioritise action to reduce their adverse environmental impacts (for further details see Appendix A.3).

The first method assesses the environmental performance of buildings on the basis of regulatory minimum environmental standards. At the end of the assessment the client will receive a certificate containing the BREEAM rating. This final score expresses the building performance in terms of credits achieved; each credit representing best practice in terms of a particular environmental issue.

The second method assesses the environmental performance of buildings by comparing the performance of each single property against its performance over time, that of its “near peer” group (including properties of the same type) and that of other properties included in the same portfolio. At the end of the assessment the client will receive a report containing the Upstream’s rating as well as finding and recommendations to improve the performance of the building.

These two methodologies are available only for assessor organisations, which work for private owners/developers aiming at improving the environmental performance of their properties. Therefore, the results of benchmarking and the methods applied are not published.

However, as far as it is possible to understand from general information available for the public about the above methodologies, the assessment of buildings does not aim at achieving a deep knowledge about the breakdown of energy consumption by end-use in the shopping centre assessed and

53 BREEAM Retail. http://www.breeam.org/retail.html, accessed August 2006.
54 Upstream. http://www.upstreamstrategies.co.uk/, accessed August 2006.

identifying energy saving opportunities, which is, instead, necessary to improve the energy efficiency of shopping centres.

An environmental benchmarking project for shopping centres, which encompasses energy, among the other environmental issues, is currently carried out by the Carbon Trust, which is an independent company funded by Government. Within this project external consultancies assess the energy performance of shopping centres and make recommendations for cost-effective energy saving measures. The assessment and report provided by the consultancies to the owners/developers of shopping centres are funded by the Carbon Trust programme. Nonetheless, results of the benchmarking programme are not yet available to the public.

Chapter 3:
METHODOLOGY

An *energy efficient building* provides the required internal environment and services with minimum energy use in a cost-effective and environmentally sensitive manner. There is, therefore, no conflict between energy efficiency and comfort (CIBSE Guide F[55]).

In the specific case of shopping centres, an energy efficient building has to provide comfort to two categories of occupants: people shopping and people working.

Therefore, the energy efficiency of shopping centres is affected by the interaction of three factors:

- the performance of the building fabric and services;
- the management of the building in terms of operation, control, maintenance and replacement of the building fabric and services, and company's energy policy;
- the occupants' expectation for comfort and awareness of energy efficiency (see Figure 3.1).

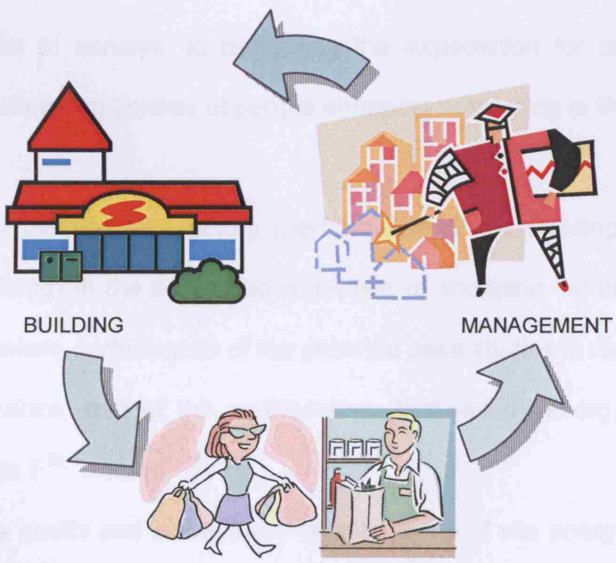

Figure 3.1. Interaction of factors affecting energy efficiency in shopping centres.

[55] *Energy efficiency in buildings.* CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 1-1.

This project aims to determine how these three elements influence the energy efficiency of shopping centres and attempts to prioritize the possible changes in one or more elements to improve the energy efficiency of shopping centres.

To achieve these targets, three cases studies have been selected.

The advantages of examining more than one case study are basically two: the same kind of information is not available for each shopping centre and different buildings of the same typology are useful for benchmarking and comparisons in order to draw some general conclusions.

For a description of the three case studies and criteria for their selection see Chapter 4.

The collected data includes:

- information about building fabric and services, and pattern of use, supplied by centre management offices, to understand the energy and environmental performance of the selected case studies;
- energy data from energy bills and sub-meters, provided by centre management offices, to assess the energy and carbon emissions performance of the selected case studies as well as break down the energy consumption of landlord's area by end-use;
- environmental data (i.e. temperature, humidity, illuminance and CO_2 concentration in the air) by monitoring, to assess the internal comfort of the selected case studies;
- occupants' responses to surveys, to determine the expectation for comfort and awareness of energy efficiency in shopping centres of people shopping or working in the selected case studies.

To establish the role of the first two factors (performance of the building fabric and services and management of the building) in the energy consumption of shopping centres, an assessment of the energy and carbon emissions performance of the selected case studies is carried out in Chapter 5.

To assess that performance, part of the methodology followed by energy audits and surveys, as illustrated in CIBSE Guide F[56], is used.

According to this, *energy audits* and *surveys* are investigations of site energy use aimed at identifying measures for cost savings, energy savings and reductions in environmental emissions. They provide the information needed to make decisions on which are the most cost-effective energy saving

[56] *Energy efficiency in buildings*. CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 18-1.

measures. Therefore, energy audits and energy surveys are two parts of the same process (for further details see Appendices B.1 and B.2).

Then, to prioritize the possible changes in one or both factors to reduce the energy consumption and carbon emissions of shopping centres, it is necessary to know in detail the energy usage in the building. This allows introducing cost-effective energy efficiency measures in shopping centres. However, as seen in Chapter 2, the only breakdown of energy consumption by end-use available at present dates back to 1992, that is 14 years ago. During this period, the building technology and strategy, as well as the management have changed. So, a new knowledge on the energy usage in shopping centres is required. For this purpose, the breaking down of energy consumption by end-use of a selected case study is attempted in Chapter 6.

To assess the performance of the building fabric and services, as well as check whether the environmental conditions match the expectation of the building occupants, a monitoring of the internal environment and subsequent analysis of the collected data have been carried out. The way in which the monitoring has been conducted and the analysis results are reported in Chapter 7.

Finally, to define and prioritize the role of the third factor (occupants' expectation for comfort and awareness of energy efficiency), a survey of people shopping and working in the selected shopping centres have been carried out at the same time of the monitoring. The development of this survey and the analysis results are discussed in Chapter 8.

Chapter 4:

CASE STUDIES

4.1. Introduction

The selected case studies are three *out-of-town shopping centres*. They are all located outside large cities: Thecentre:mk, between London and Birmingham, Lakeside Shopping Centre, near London, and Meadowhall Centre, near Sheffield.

The choice of out-of-town case studies, instead of in-town ones, is driven by the continuous development in the U.K of this typology, although the country is currently undergoing a wave of retail-led town centre redevelopment. Most new retailing facilities are located outside the town centres, as they are easily accessible to private cars and the demand for additional retail floor space, created by the economic growth, is easily satisfied at lower costs than inside urban centres. This is the current situation, although the planning system is preventing this development from being located out-of-town[57].

According to the shopping centre classification by size based on criteria of the International Council of Shopping Centers (ICSC)[58], the selected case studies are all *super regional centres*, which means that they deal in general merchandise and fashion, with more variety and assortment of regional shopping centres, and have a size over 800,000 ft^2.

External view of Thecentre:mk (1), Lakeside Shopping Centre (2) & Meadowhall Centre (3).

[57] Bach M. and Thurstain-Goodwin M. of Geofutures. *The Future of Retail Property. In-town or out-of-town?*. Research project carried out by the British Council of Shopping Centres (BCSC). http://www.bcsc.org.uk/research/FORP/project06.htm, accessed August 2006.

[58] DeLisle J. R. *U.S. Shopping Center Classifications: Challenges and Opportunities.* Research Review. Vol. 12, Issue No. 2, 2005. International Council of Shopping Centers (ICSC). Pages 96-101.

4.2. Site details

Thecentre:mk is a hybrid of an out-of-town and in-town centre in the heart of Milton Keynes (the fastest growing city and one of the five richest district in the Country), which is the dominant regional destination for retail and leisure between London and Birmingham, located mid-way between these two cities, on the Oxford to Cambridge high technology arc, and one of the leading retail and leisure destinations in the U.K.

Together with Midsummer Place and Xscape, it offers over 166,311 m^2 (1,790,000 ft^2) of retail floor space, making it one of the largest shopping centres in the U.K.[59]. It is also the longest covered centre in Europe.

Lakeside Shopping Centre is located in West Thurrock, Essex, just beyond the eastern boundary of Greater London.

Built on a redundant chalk quarry, it was the first regional shopping centre in the south of England.

Together with the adjoining Retail Park, it now forms the largest shopping area in a single location within Europe and second only to one in Canada, with almost 241,568 m^2 (2,600,000 ft^2) of retail floor space on a site of 200 acres[60].

Meadowhall Centre is located 4.8 km (3 miles) north-east of Sheffield city centre (the fourth largest city in the U.K.) in the county of South Yorkshire, within the Lower Don Valley.

Built on the site of a derelict steelworks, alongside the River Don, it attracts visitors from many surrounding towns and Country's major cities, including: Sheffield and Manchester, to the west; Leeds, Barnsley, Huddersfield, York and Harrogate to the north; Rotherham, Doncaster and Worksop to the east; Nottingham, Derby, Chesterfield and Leicester to the south.

Together with its surrounding area, including a Retail Park of 19,140 m^2 (206,000 ft^2), is one of the leading shopping and leisure destinations in the U.K.[61].

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[59] *Thecentre:mk Fact File*. July 2004. Page 12. Thecentre:mk. http://www.thecentremk.com/Documents/fact-file-July-04.pdf, accessed August 2006.

[60] "Lakeside Shoppping Centre". Wikipedia. http://en.wikipedia.org/wiki/Lakeside_Shopping_Centre, accessed August 2006.

[61] *Meadowhall Fact Pack*. Smith Young Property Consultant. April 2005. Page 1.

Thecentre:mk has completed major refurbishment in 2000. However, some improvements in the building service system are currently underway.

Lakeside Shopping Centre has recently undergone major refurbishment, including new flooring, lighting, ceiling and glass roofs, which allow much more natural light into the shopping centre, faster elevators and additional escalators.

In Meadowhall Centre a mall refurbishment is currently underway and is due to finish in early 2007. It includes major improvements to the architecture, lighting, HVAC system, escalators and signage.

The three shopping centres carry out a non-smoking policy across the whole building, except for an area of the food court in Lakeside Shopping Centre and a few eating areas in Meadowhall Centre.

For further details about the buildings see Appendix C.1, C.2 and C.3.

4.3. Architectural description

The selected case studies are enclosed malls, which means that they are entirely inside a roofed structure, so that access to the mall is controlled by a limited number of entrances and most stores are accessible only via interior corridors, and have adjacent parking.

The same shopping centres differ in number of storeys: Thecentre:mk has one floor; Meadowhall Centre, two floors; Lakeside Shopping Centre, three floors.

Thecentre:mk has a rigid grid and framework, with a glass-and-steel envelope. It is symmetrical in plan, divided into three by two main malls 12 m wide, 14 m high, crossed by eight high subsidiary crosswalks 12 m wide at 90 m intervals connecting the car parks and public transport on the perimeter. For a plan of the building see Figure 7.1.

Lakeside Shopping Centre comprises two principal shopping levels interconnected by glazed concourses, 46 lifts, 18 escalators and stairs, and crossed by shorter crosswalks. A third level within the central section contains a food court and the centre manager's offices. For plans of the building see Figure 7.2.

Meadowhall Centre is built on two levels with a crescent shape. The cranked long mall axis is crossed by shorter transverse axis. The changes of mall direction are emphasized by glazed domes. Vertical movement is maximised through 24 lifts and 10 escalators located throughout the centre. The malls are arranged into six themed areas, each with a distinctive character. In particular, High Street is the backbone of the centre, with its about 400 m length. For plans of the building see Appendix C.4.

In Thecentre:mk large stores are located along the centre band with frontages on to both malls, and smaller units in the outer frontages.

In Lakeside Shopping Centre and Meadowhall Centre anchor multiple stores are located at ends and key intermediate points along the malls, while smaller units along the malls in the outer frontages.

In the three shopping centres, anchor stores are often multi-storey.

In all shopping centres catering facilities are distributed around the shopping area to include cafés and restaurants.

However, in Lakeside Shopping Centre and Meadowhall Centre there is also a food court.

In Lakeside Shopping Centre the food court, with 1,100 seats under the large domed atrium, forms a central attraction.

In Meadowhall Centre the Oasis Food Court is one of the largest food courts in Europe, with 2,250 seats on two levels. It also contains an 11 screen cinema, a giant videowall, a bandstand stage for live entertainment and retail promotions, and usually hosts family entertainments.

In Thecentre:mk and Lakeside Shopping Centre there are also other very large public spaces within the building.

In the first centre, Middleton Hall has 2,400 m^2 of floor space for the mounting of major promotions, exhibitions and public entertainment and Queens Court, of 2,800 m^2, is a garden courtyard.

In the second centre, the central atrium, a 219 m^2 space, is the heart of the shopping centre. It is customised to create a venue for a wide variety of special events ranging from exhibitions and concerts to fashion shows on catwalks and TV shows.

In addition, Meadowhall offers several customer events including celebrity appearances, fashion shows, etc.

All these events and those taking place in the food courts involve an increase in the energy consumption.

The three case studies are provided with natural lighting.

In Thecentre:mk the main malls are naturally lit through a full glazing at the third level on the internal side and at both second and third level on the external sides; there is only a subdued lighting level after dark, the shop fronts being expected to be the main lighting source. The cross malls have predominantly artificial lighting.

In Lakeside Shopping Centre and Meadowhall Centre the malls and atriums receive natural light through glazed roof and domes respectively, and artificial light from luminaires mounted on perimetric walls and ceilings.

The presence of natural lighting in all the buildings allows planting and trees in the main malls and atriums.

(For images of the case studies, see Appendix C.5.)

4.4. Building services description

In Thecentre:mk artificial lighting within the common areas is provided through high level lights plus some additional low level lights.

High level lighting is controlled by a natural light level base system. Some high and low level lighting is switched off during opening hours, before dark.

The security staff is responsible for switching the lighting within the common areas as appropriate through a lighting management system.

A large number of the lights remain switched on continuously between 22:00 and 8:00, when the centre is closed to the public, to satisfy a combination of cleaning and security requirements, so consuming a large proportion of the site power usage.

In Lakeside Shopping Centre the majority of the lighting control is based on an auto time on/off basis.

In Meadowhall Centre high level mall lighting is on for the following periods with photocell control to switch off lamps when natural lighting through the rooflights is sufficient: from 06:15 to 08:00 and from 10:00 to 21:30 during weekdays, and from 09:00 to 19:30 on weekends. Low level down-lighters are controlled from 05:00 to 08:00. Decorative lighting is controlled from 05:00 to midnight.

Thecentre:mk is provided with mechanical ventilation and heating, but not cooling, while Lakeside Shopping Centre and Meadowhall Centre are fully air-conditioned.

In Thecentre:mk a combined ventilation and heating system of ducted warm air provides a typical space temperature of around 19 °C within the common areas, a design temperature of 16 °C at -1 °C externally and a ventilation rate of 12 ac/h. Shops draw their air directly through external walls and roofs.
Each indirect gas fired warm air heater, operating only during the winter months, has individual air circulation fan motors and 100 % air circulation.
The units are switched on/off via individual time switches local to each of the heaters. The time switches are set to enable the heaters at 6:00 a.m. and off as the centre closes. The heaters are currently equipped with on/off burners only with the fans operating constantly irrespective of the burner operation.
The heaters are controlled via thermostats in the return air duct. The return air temperature is often influenced by draughts from the entrance doors and is not indicative of the actual space temperature which can be influenced by solar gain and other heat gains from the shops and centre visitors.

In Lakeside Shopping Centre conditioned air is provided to the mall via individual air handling units (AHUs) with a full fresh air only configuration. The AHUs filter, heat and cool the air, the heating being provided by integral direct gas fired heater batteries, the cooling being provide by a direct expansion (DX) cooling coil piped directly to an air cooled chiller.
The operational strategy of the ventilation system is to supply air at high level on each of the mall floors with extraction of the air from the mall via extract points at the rear of retail units sized at 1,000

m^2 floor area and below. The extraction of air in this manner maintains a positively pressurised mall and helps to avoid cross contamination of air between each of the retail units. All retail units above 1,000 m^2 must provide their own means of ventilating their space.
Existing natural roof vents for smoke control could be used to provide night purge ventilation, and cooling by natural ventilation when the external temperature is lower than the internal one, both in not rainy days. In this way, the energy consumption might be reduced, considering that at present the HVAC system operates for the whole day. During the night the only one that has access to the building is the security staff, for whom the provision of fresh air by natural ventilation would probably be sufficient. Therefore, the building could have a mixed-mode ventilation system, instead of being fully air-conditioned.

In Meadowhall Centre the mall areas are heated and ventilated with a mechanical ventilation system, while certain mall areas, the Oasis and management suite are also cooled.
The AHUs, which serve the malls, are generally warm air systems that deliver full-fresh air, with no recirculation. Each unit is fitted with a run-around-coil for exhaust air heat recovery. Heating is achieved with a direct gas fired heater integral to the AHU. The system heats the malls to 19 °C, while back of house areas are not heated. The warm air system operates until half an hour after trading; then returns to frost protection control. Warm air is supplied to the malls through ceiling diffusers and extracted at high level.
As regards the air-conditioned Oasis and some mall areas, the AHUs are fitted with cooling coils and recirculation. The AHUs are served from water chillers and individual boiler units. The AHU supply and exhaust fans are fitted with variable speed drives, which is utilized to put the plant into a set back condition, say 40% maximum flow (to preserve acceptable air distribution patterns) at periods of light loading (no demand for cooling) and/or when the centre has a low occupancy.

In Lakeside Shopping Centre and Meadowhall Centre a building management system (BMS) controls the building service system and, in particular, the operation of lighting, HVAC, building transportation, fire alarm and security systems. In Thecentre:mk a BMS is on the point of being introduced.

Chapter 5:

ENERGY AND CARBON EMISSIONS PERFORMANCE

5.1. Introduction

The energy and carbon emissions performance gives a measure of the energy efficiency of buildings. On the basis of the analysis of selected case studies, the aim of this chapter is to:

- establish current energy consumption and carbon emissions of shopping centres;
- identify trends in energy consumption and carbon emissions of shopping centres and check that these matches actual occupancy and seasonal changes in weather;
- identify main sources of energy use and CO_2 production by comparing current energy consumption and carbon emissions with historical data and among case studies.

5.2. Collection of data

The calculation of the energy and carbon emissions performance is based on monthly consumption data, provided by the centre management offices. These data are in the form of transcribed extracts on Excel spreadsheets of original energy bills, which are the principal and essential source of information on energy input.

The data refer to a full year (2005), the most recent audit period, and the first six months of the following year (2006).

Where the previous year's energy data (often referred to as historical data) are available, a comparison with the audit year should be made, as this may indicate any major overall trends. However, this was not thoroughly possible for lack of complete series of data. Nevertheless, as the selected shopping centres are currently carrying out or have recently completed a refurbishment of their building services, 2006 data are useful to see the first results of these improvements.

All energy data and carbon emissions results are summarized in Appendices D.1 to D.3.

All energy terms are in delivered energy, which means that are read from the meter of the supplier. Each site has more than one supplier.

The data on energy use gathered do not refer exclusively to the buildings. In Thecentre:mk the energy consumption refers to the building and the internal court. In the internal court the energy is supplied for artificial lighting. In Lakeside Shopping Centre and Meadowhall Centre the energy use refers to the building and car parks. In the car parks the energy is supplied for artificial lighting.

In Thecentre:mk and Meadowhall Centre it is not possible to disaggregate the figures as no sub-metering is carried out in the two zones. In Lakeside Shopping Centre the figures were provided already aggregated; so it is not known if a breakdown by area was possible.

Usually sub-meter readings, which are a key source of energy data, can help to identify areas of high consumption.

In addition, energy companies supplying electricity and gas should be able to provide half hourly data in electronic form allowing analysis of daily/weekly/monthly demand patterns. Nevertheless, these data are not available.

To compare the variation of energy consumption and carbon emissions of the shopping centres with the changes in weather, monthly weather data has been gathered from the MET Office[62]. These only refer to 2005 year; 2006 data are not yet available, as the series is not completed.

Each shopping centre has been associated to the nearest station as follows:

- Thecentre:mk: Brize Norton,
- Lakeside Shopping Centre: Heathrow,
- Meadowhall Centre: Woodford.

[62] Met Office. http://www.metoffice.com/, accessed August 2006.

5.3. Energy analysis of data

In this chapter, data of energy consumption from individual sites are analysed separately and then compared among each others.

The overall performance of each building is crudely expressed as a performance indicator, in energy consumption (kWh/m^2) per year and carbon emissions (kgCO_2/m^2) per year.

The analysis is normally performed on annual data, allowing comparison with published benchmarks to give an indication of efficiency. Some of these benchmarks are shown in section 20 of CIBSE Guide F[63]. Others are usually available from the Carbon Trust's publications[64]. "Typical" and "good practice" benchmarks exist for different kinds of building and can be used as a target. Although they are fairly general, they give a more absolute measure of how certain types of building should perform, rather than a relative comparison with past performance.

Nonetheless, these benchmarks are not available for shopping centres. Therefore, performance indicators are used to compare the case studies among each others. For this purpose, they are normalized in terms of treated floor area.

According to CIBSE Guide F[65], the *treated floor area* (TFA) is given by the *gross floor area*, which is the total building area measured inside external walls, less plant rooms and other areas not directly heated or cooled (e.g. stores).

In addition, according to the Upstream's methodology for sustainability benchmarking of shopping centres[66], the *gross floor area* excludes car parks, even if they are covered.

CIBSE Guide F[67] suggests that in general TFA is to be preferred, although the available energy benchmarks for retail buildings are usually based on *sales floor area*, also known as *net lettable floor area*, which is the gross floor area less common areas and ancillary spaces.

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[63] *Energy efficiency in buildings*. CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 20-1 – 20-14.

[64] Carbon Trust. http://www.thecarbontrust.co.uk/default.ct, accessed August 2006.

[65] *Energy efficiency in buildings*. CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 13-1.

[66] *2005 Environmental Benchmarking for Shopping Centres*. Upstream. London. 2005. Page 33.

[67] *Energy efficiency in buildings*. CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 13-1 and 20-1 – 20-5.

Upstream's methodology also specifies that the *net lettable floor area* is all the tenant occupied area, excluded car parks, and the *common area* includes, mall areas, staircases, enclosed service yards, storage areas, plant rooms, centre management office area, escalators and lifts.

The aim of this part of the study is to assess the energy and carbon emissions performance of the common areas in shopping centres, which cover a considerable space in the building and are managed by the landlord. Therefore, the use of a "physical" figure, like the TFA, for normalising the data, instead of a "marketing" one, like the net lettable floor area, is considered more appropriate.
Moreover, the available data of energy consumption refers to the common areas of the buildings and not to the sales floor areas, which have separate suppliers and energy bills from the landlord areas.

As a detailed assessment of what makes up the common area is not possible for the selected case studies, the TFA is calculated by subtracting the net lettable area from the gross floor area.
The estimated common areas (afterwards indicated as TFA) considered in the three case studies are the following:

- Thecentre:mk: 32,400 m^2 [68],
- Lakeside Shopping Centre: 49,240 m^2 [69],
- Meadowhall Centre: 33,150 m^2 [70].

Sometimes indicators are adjusted according to weather and/or occupancy and are called "normalised performance indicators" (NPIs). This "normalisation" is intended to improve comparison between buildings in different climatic regions or with different occupancy patterns. However, this approach should be used with care as it can often distort the data and mask real patterns in consumption.
In this study, it is assumed that differences in weather and occupancy are not so relevant, based on the data provided by the MET Office[71] and a general knowledge about the occupancy pattern obtained by personal experience and managers' interviews. In fact, all shopping centres usually have peak occupancy in the same periods, such as during sales or Christmas, except for special events that may

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[68] From *Assessment of Specific Energy Savings Opportunities for The Centre MK.* Briar Associates. The Carbon Trust Programme. 16th April 2006. Page 1.
[69] From Excel spreadsheet provided by the Lakeside Centre Management.
[70] From *British Land Energy Benchmarking Phase 3. Energy Audits.* Ove Arup & Partners Ltd. British Land Carbon Management Programme. 20th April 2006. Page 42.
[71] Met Office. http://www.metoffice.com/, accessed August 2006.

take place in individual malls. Nonetheless, these occasional events can be detected from the energy consumption profiles, if they last for long time and/or deeply affect the energy use; otherwise, they can be overlooked in this kind of analysis.

The overall performance of each building is also analysed by fossil fuel and electricity. The percentage breakdown of total energy consumption by energy type is determined to indicate its relative significance.

The three case studies use the same kind of energy:

- *electricity* for ventilation and cooling (air-conditioning), lighting, building transportation systems and small power (e.g. catering and office equipment);
- *natural gas* for heating and hot water.

To work out the carbon emissions associated with energy use, the following carbon emissions factors, taken from a Carbon Trust's leaflet[72], are applied:

- grid electricity: 0.43 $kgCO_2/kWh$,
- natural gas: 0.19 $kgCO_2/kWh$.

Obviously, each unit of electricity results in at least two times more CO_2 being emitted as the direct use of natural gas in buildings. In addition, a unit of electrical energy is more expensive than the equivalent amount of energy obtained through the consumption of fossil fuels in the building's heating system. Therefore, separate indicators are used for electricity and natural gas consumption. Where a single indicator is required, the electricity and natural gas consumption are converted to $kgCO_2$ and the two numbers added together.

Section 20 of CIBSE Guide F[73] provides separate benchmarks for electricity and fossil fuels to allow for the widely different costs and CO_2 emissions per unit of delivered energy. Nevertheless, as previously said, these benchmarks are not available for shopping centres.

[72] *Energy and carbon conversions*. Carbon Trust. London. March 2006. Page 3.
[73] *Energy efficiency in buildings*. CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 20-1 – 20-14.

5.3.1. Thecentre:mk

In 2005 Thecentre:mk consumed 7,511,184 kWh of energy (232 kWh/m^2 (TFA)): 3,771,039 kWh from electricity (116 kWh/m^2 (TFA)) and 3,740,145 kWh from gas (115 kWh/m^2 (TFA)). So, the delivered energy comes almost equally from electricity and gas (see Figure 5.1).

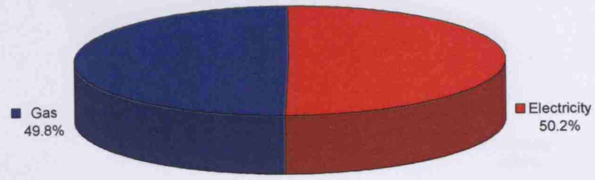

Figure 5.1. Breakdown of annual energy consumption by fuel (2005).

Comparing the electricity delivered in 2005 and 2006, in Figure 5.2 it is possible to see a decrease of about 1 kWh/m^2 in the following year, except in January. This reduction may be indicative of the changes the site has made to the lighting operation.

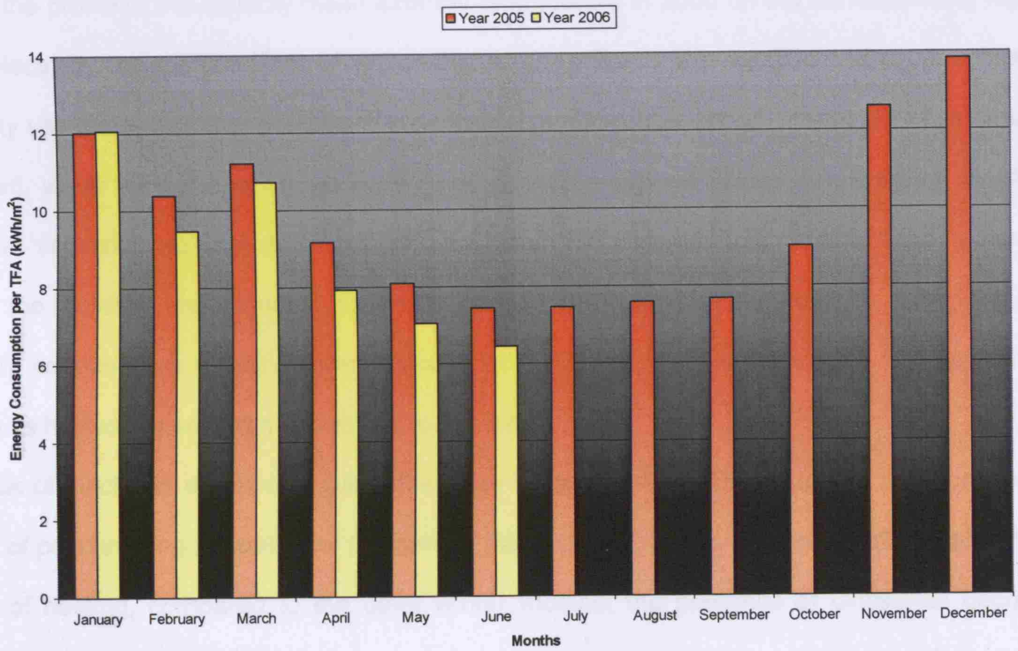

Figure 5.2. Annual profiles of electricity consumption per TFA (2005 and 2006).

This cut in electricity use during 2006, except in January, is reflected in a decrease of carbon emissions per TFA of about 0.5 $kgCO_2/m^2$ (see Figure D.4.1 in Appendix).

The total CO_2 emissions in 2005 were 72.0 $kgCO_2/m^2$ (TFA): 50 $kgCO_2/m^2$ from electricity and 22.0 $kgCO_2/m^2$ from gas (69 and 31% respectively, as shown in Figure 5.3).

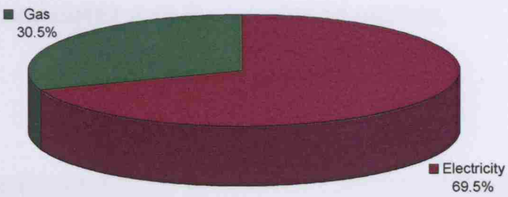

Figure 5.3. Breakdown of annual carbon emissions by fuel (2005).

As monthly data of gas consumption for the years 2005 and 2006 are unavailable, it is not possible to make a comparison of gas and total energy consumption between the two years, as done for electricity.

Plotting the profile of the monthly mean external temperature in 2005 on the corresponding histogram of the electricity consumption per TFA (see Figure 5.4), it was expected to find an increase in the electricity use during summer period and a decrease during winter period. In fact, as it is mechanically ventilated, when the external temperature rises up to the highest values, the building should need additional ventilation to cool down the air and, when the external temperature drop to the lowest values, the building should need additional heating; the latter is produced by gas. Instead, the electricity consumption remains almost steady at the lowest values from June to September and reaches its highest values from November to January.

The peak of electricity demand in December may be explained by three factors: the increase in the amount of people going shopping for Christmas, that probably implies the use of additional ventilation, instead of heating, compared to the other winter months; the presence of Christmas decorations, especially lightings, which require additional electricity; and the placement in the shopping centre of a winter ice rink, which requires extra energy for cooling.

The variations in the profile of electricity consumption may be due to the lighting operation. During summer period the solar radiations are higher and the days are longer. In this period, most of the common area is naturally lit up through the glazing. Only a few lights are on in the arcades that are not light up by sun, especially those transversal, as well as in the offices, toilets and facilities. On the opposite, during winter period the solar radiations are lower and the days shorter. So, artificial lighting is required everywhere in the shopping centre.

In addition, in the HVAC system the greatest consumption of electricity is due to the operation of fans. During colder period the use of electricity to run the fans associated with the heating system may offset that to operate the fans associated with the ventilation system.

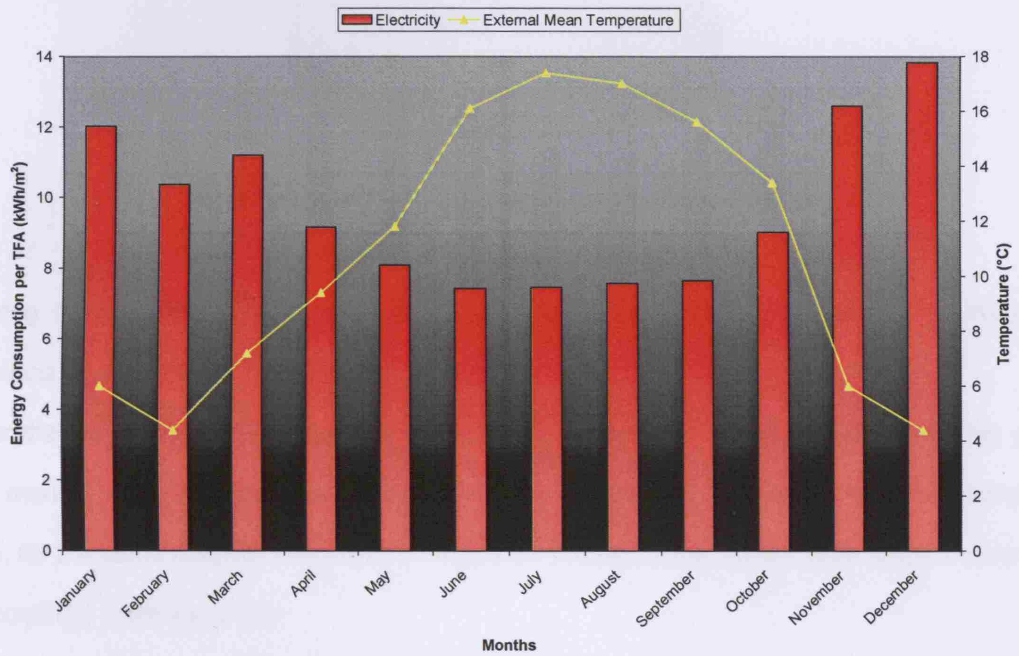

Figure 5.4. Annual profiles of electricity consumption per TFA and external mean temperature (2005).

Therefore, there are two main issues which affect energy use at the site.

The main factor which influences both gas and electricity usage is the variation in external weather conditions together with the internal temperature required.

Then, electricity usage is influenced by the operation of the lighting and fans associated with the heating units. It is also affected by any event that is occurring at the centre, especially those that attract more people than the usual.

5.3.2. Lakeside Shopping Centre

In 2006 Lakeside Shopping Centre consumed 11,728,197 kWh of energy (238 kWh/m^2 (TFA)): 7,449,351 kWh from electricity (151 kWh/m^2 (TFA)) and 4,278,846 kWh from gas (87 kWh/m^2 (TFA)). So, the delivered energy comes for about two thirds from electricity and one third from gas (see Figure 5.5). However, this breakdown is referred only to half year, the first six months.

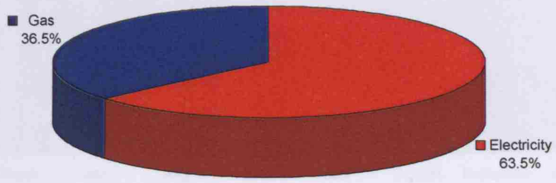

Figure 5.5. Breakdown of annual energy consumption by fuel (2006).

Comparing the electricity and gas delivered in 2006, in Figure 5.6 it is possible to make some assumptions on the reasons of this energy profile.

In winter the increasing demand for heating implies a higher use of gas. In particular, this year the coldest months were February and March to which correspond the highest gas consumption. In addition, for the same reasons expressed in regard to Thecentre:mk, winter days require more lighting and accordingly more electricity.

During midseason less heating and lighting are required, and cooling is not yet so necessary. As a consequence, the use of gas and electricity start to decrease. In particular, the electricity usage maintains quite steady between April and May.

In summer the increasing demand for cooling produces a rise in the use of electricity. Instead, the gas usage continues to reduce. In addition, part of the lights in the common spaces that are naturally lit up are on during the day, even when artificial lighting is not required.

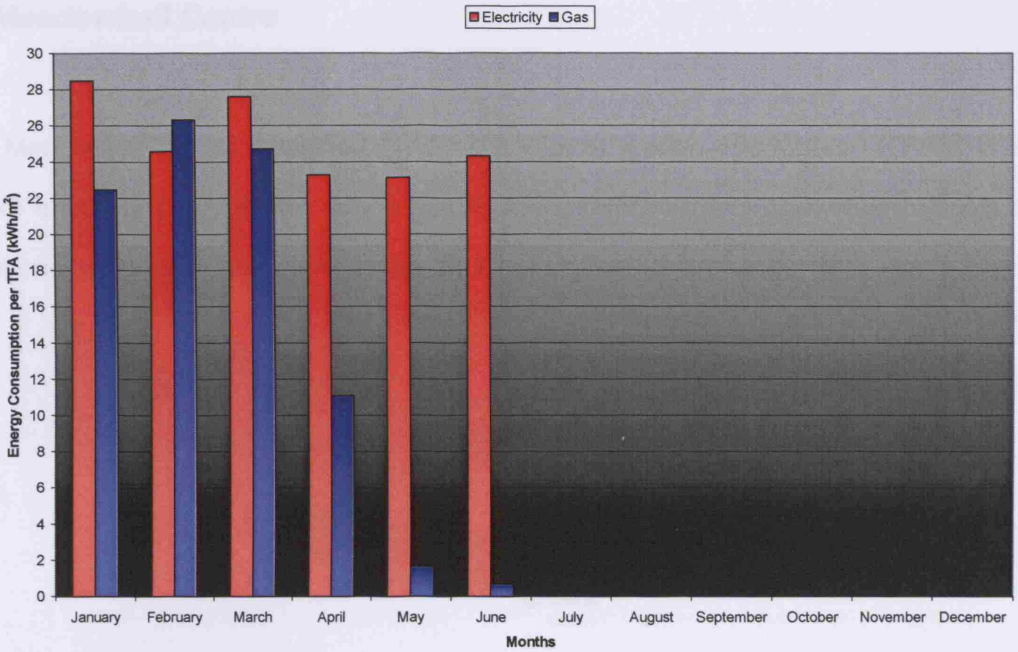

Figure 5.6. Annual profile of energy consumption per TFA (2006).

The profile of electricity and gas use is obviously reflected by the variations of carbon emissions (see Figure D.4.2 in Appendix).

The total CO_2 emissions in the first six months of 2006 were 81.6 $kgCO_2/m^2$ (TFA): 65.1 $kgCO_2/m^2$ from electricity and 16.5 $kgCO_2/m^2$ from gas (80 % and 20 %, as shown in Figure 5.7).

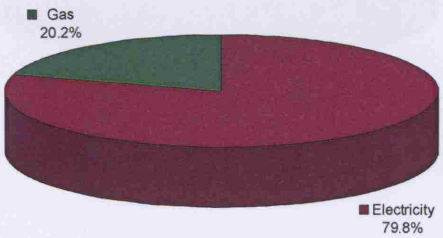

Figure 5.7. Breakdown of annual carbon emissions by fuel (2006).

5.3.3. Meadowhall Centre

In 2005 Meadowhall Centre consumed 11,923,220 kWh of energy (360 kWh/m^2 (TFA)): 11,259,262 kWh from electricity (340 kWh/m^2 (TFA)) and 663,958 kWh from gas (20 kWh/m^2 (TFA)). So, the delivered energy comes for about 94 % from electricity and only 6 % from gas (see Figure 5.8).

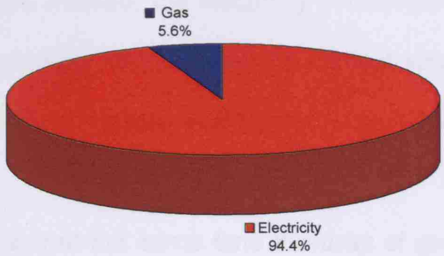

Figure 5.8. Breakdown of annual energy consumption by fuel (2005).

In 2006 the centre consumed 5,918,257 kWh of energy (179 kWh/m^2 (TFA)): 5,461,103 kWh from electricity (165 kWh/m^2 (TFA)) and 457,154 kWh from gas (14 kWh/m^2 (TFA)). So, the delivered energy comes for about 92 % from electricity and 8 % from gas (see Figure 5.9).

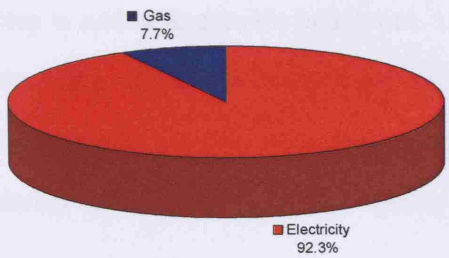

Figure 5.9. Breakdown of annual energy consumption by fuel (2006).

The breakdown of the energy consumption is quite similar in both years. However, the breakdown in 2006 is referred only to half year, the first six months.

Comparing the electricity and gas delivered in 2005 and 2006 in Figures 5.10 and 5.11 respectively, it is possible to make some assumptions on the reasons of these energy profiles.

Plotting the profile of the monthly mean external temperature in 2005 on the corresponding histogram of the electricity consumption per TFA (see Figure 5.10), it was expected to find two opposite situations for the two types of fuel: an increase in the electricity use during summer period and a decrease during winter period as well as a rise in the gas usage during winter period and a reduction during summer period. In fact, as it is fully air-conditioned, when the external temperature rises up to the highest values, the building should need additional cooling, that is produced by electricity, and almost no heating, except for the hot water supply; when the external temperature drops to the lowest values, the building should need additional heating, that is produced by gas, and almost no cooling, except for the most crowded days. Instead, the electricity consumption remains almost steady at the lowest values from June to September and reaches its highest values from November to January, while the gas consumption seems to respect this theory, except in three months (March, July and December).

The peak of electricity demand and at the same time the drop of gas demand in December may be explained by the same two factors found for Thecentre:mk: the increase in the amount of people going shopping for Christmas, that probably implies the use of additional ventilation and cooling, instead of heating, compared to the other winter months; and the presence of Christmas decorations, especially lightings, which require additional electricity.

The variations in the profile of electricity consumption may be due to the lighting operation, as in Thecentre:mk. During summer period most of the common area is naturally lit up through the glazing, even though some artificial lighting is added to provide brightness. Lights are on in the arcades that are not light up by sun, as well as in the offices, toilets and facilities. However, the system of artificial lighting is equipped with dimming control system to save energy and avoid glare or uncomfortable brightness. On the opposite, during winter period artificial lighting is required everywhere in the shopping centre.

In addition, in the HVAC system the greatest consumption of electricity is due to the operation of fans, as in Thecentre:mk. During colder period the use of electricity to run the fans associated with the heating system may offset that to operate the fans associated with the cooling system.

Instead, the rise of the gas consumption in July 2005 and June 2006 might be explained by the execution of the works of refurbishment.

The negative value of gas in May is due to estimated readings, provided by the centre management office.

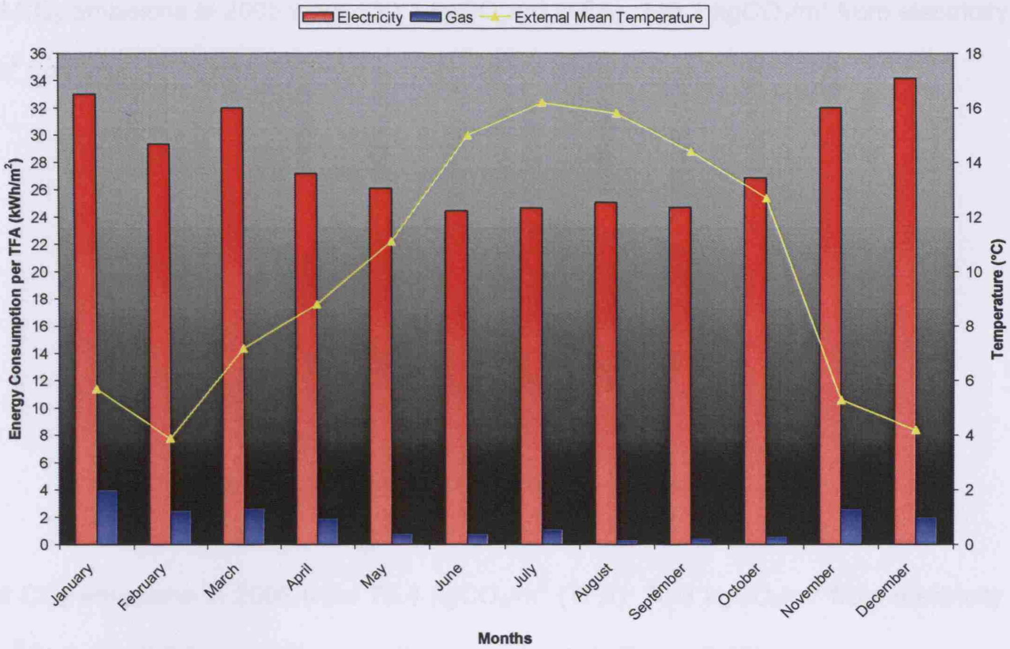

Figure 5.10. Annual profiles of energy consumption per TFA and external mean temperature (2005).

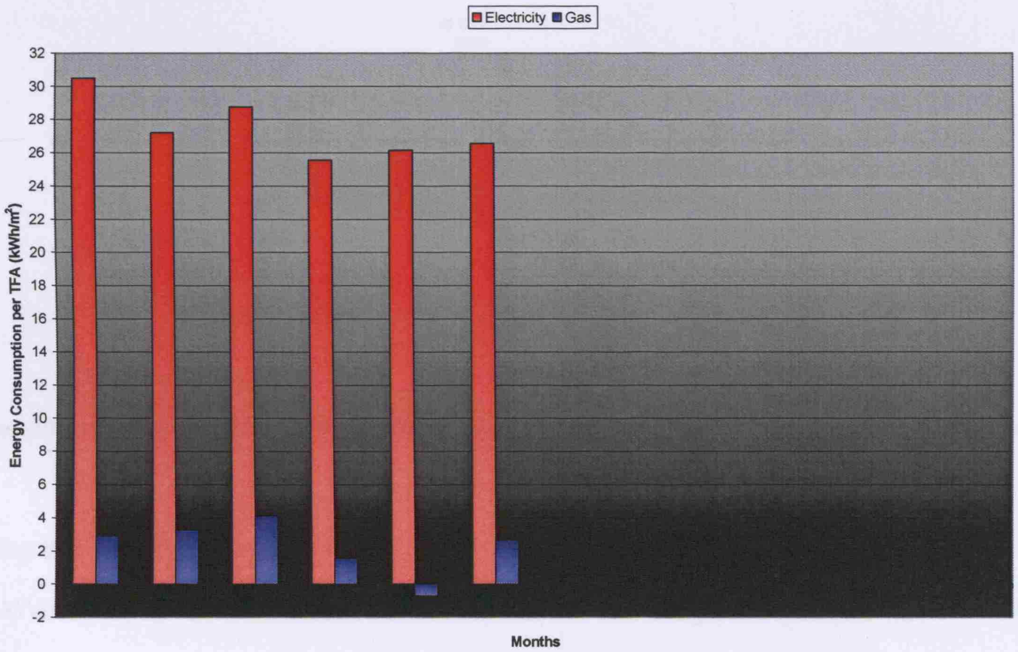

Figure 5.11. Annual profile of energy consumption per TFA (2006).

The profiles of electricity and gas use are obviously reflected by the variations of carbon emissions (see Figures D.4.3 and D.4.4 in Appendix for 2005 and 2006 respectively).

The total CO_2 emissions in 2005 were 150.1 $kgCO_2/m^2$ (TFA): 146.1 $kgCO_2/m^2$ from electricity and 4.0 $kgCO_2/m^2$ from gas (97 % and 3 % respectively, as shown in Figure 5.12).

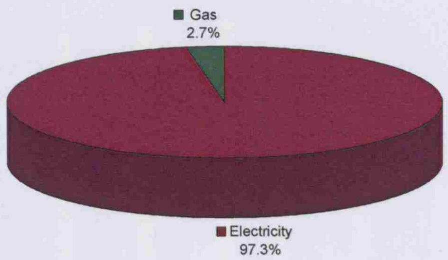

Figure 5.12. Breakdown of annual carbon emissions by fuel (2005).

The total CO_2 emissions in 2006 were 73.4 $kgCO_2/m^2$ (TFA): 70.8 $kgCO_2/m^2$ from electricity and 2.6 $kgCO_2/m^2$ from gas (97 % and 3 % respectively, as shown in Figure 5.13).

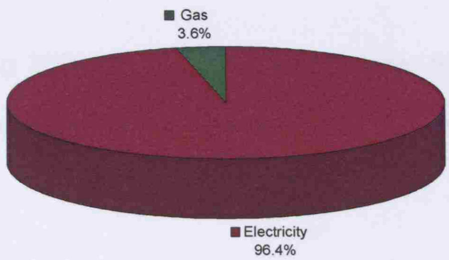

Figure 5.13. Breakdown of annual carbon emissions by fuel (2006).

The breakdown of carbon emissions is quite similar in both years, like that of the energy consumption.

Comparing the electricity delivered in 2005 and 2006, in Figure 5.14 it is possible to see a decrease of about 1 kWh/m^2 in the following year, except in May, when the usage is almost the same in both year, and June, when the use has increased compared to the previous year. This rise may be indicative of the refurbishment that part the site is undertaking in these two months.

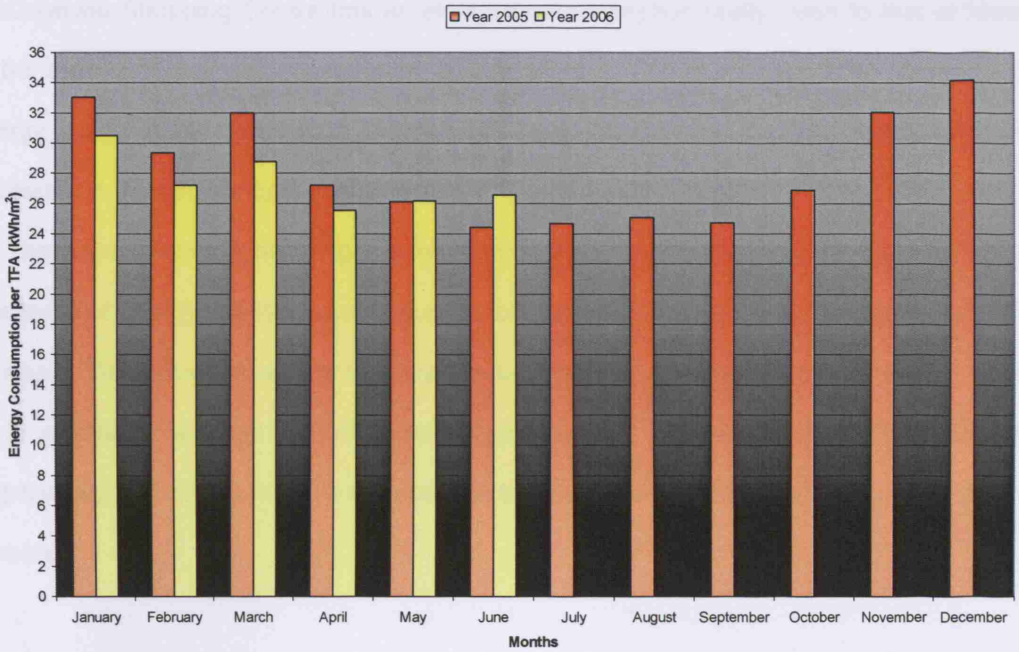

Figure 5.14. Annual profiles of electricity consumption per TFA (2005 and 2006).

The cut in electricity use during 2006, except in May and June, for the same reasons mentioned above, is reflected in a decrease of carbon emissions per TFA of about 2.0 $kgCO_2/m^2$ (see Figure D.4.5 in Appendix).

5.3.4. Comparison of energy and carbon emissions performance among case studies

Table 5.1 shows a summary of the annual energy consumption and carbon emissions per TFA in Thecentre:mk, Lakeside Shopping Centre and Meadowhall Centre.

As it is possible to notice, the total energy consumption and carbon emissions in Meadowhall Centre is higher than in Thecentre:mk during 2005 and lower than in Lakeside Shopping Centre during 2006.

However, the breakdown of energy use and related carbon emissions by fuel differs in the three shopping centres. Thecentre:mk has the lowest electricity usage and Meadowhall Centre the highest in 2006 and 2005 too, supposing a similar trend of energy use during both years in Lakeside Shopping Centre.

On the opposite, Meadowhall Centre has the lowest gas usage.

In 2006 Lakeside Shopping Centre has an electricity consumption really close to that of Meadowhall Centre, but a much higher gas consumption compared to it. This makes Lakeside Shopping Centre's total energy usage much higher than Meadowhall Centre's. Anyway, the total carbon emissions are not so different in the two shopping centres.

In 2005 Thecentre:mk has a higher gas consumption than Meadowhall Centre and probably in 2006 too, if the trend of energy use is the same during both years in the two shopping centres respectively.

On the whole, Thecentre:mk seems to have the best energy and carbon emissions performance in relation to electricity, at least in 2006, probably because it has not cooling, unlike the other two shopping centres, but no conclusions are possible to achieve in regard to gas and overall performance in both years.

Table 5.1. Summary of the annual energy consumption and carbon emissions per TFA in Thecentre:mk, Lakeside Shopping Centre and Meadowhall Centre (2005 and 2006).

	Energy Consumption per TFA (kWh/m^2)			Carbon Emissions per TFA ($kgCO_2/m^2$)		
Shopping Centre	**Electricity**	**Gas**	**Total**	**Electricity**	**Gas**	**Total**
Year 2005						
Thecentre:mk	116	115	232	50.0	22.0	70.0
Lakeside	–	–	–	–	–	–
Meadowhall	340	20	360	146.1	4.0	150.1
Year 2006						
Thecentre:mk	54	–	–	23.1	–	–
Lakeside	151	87	238	65.1	16.5	81.6
Meadowhall	165	14	179	70.8	2.6	73.4

According to the available data, by comparing the annual profiles of energy consumption among case studies, it is possible to generalize some assumption about a possible energy breakdown by use in shopping centres as well as highlight the peculiarities related to energy usage in each of them.

Figures 5.15 and 5.16 show that the three shopping centres have the same annual profile of electricity consumption in both years.

The only exception is given by the electricity use in Thecentre:mk between May and June 2006. Here the usage decreases, instead of increasing as in the other two shopping centres, because there is a lower use of artificial lighting in the common area naturally lit up.

In addition, the shopping centres show the same anomaly: the rise of the electricity consumption in March of both years. The reason of this might be hidden under the interaction of different factors depending on the external climatic conditions, such as heating, ventilation, cooling and lighting.

In general, the shopping centres consume more electricity in winter period than in summer period. This is due to the higher demand of artificial lighting and energy to run the fans associated with the heating system; the latter may offset the electricity demand to operate the fans associated with the ventilation and/or cooling system.

In particular, the peak of electricity demand in December may be explained by two factors: the increase in the amount of people going shopping for Christmas, that probably implies the use of additional ventilation and/or cooling, compared to the other winter months; and the presence of Christmas decorations, especially lightings, which require additional electricity.

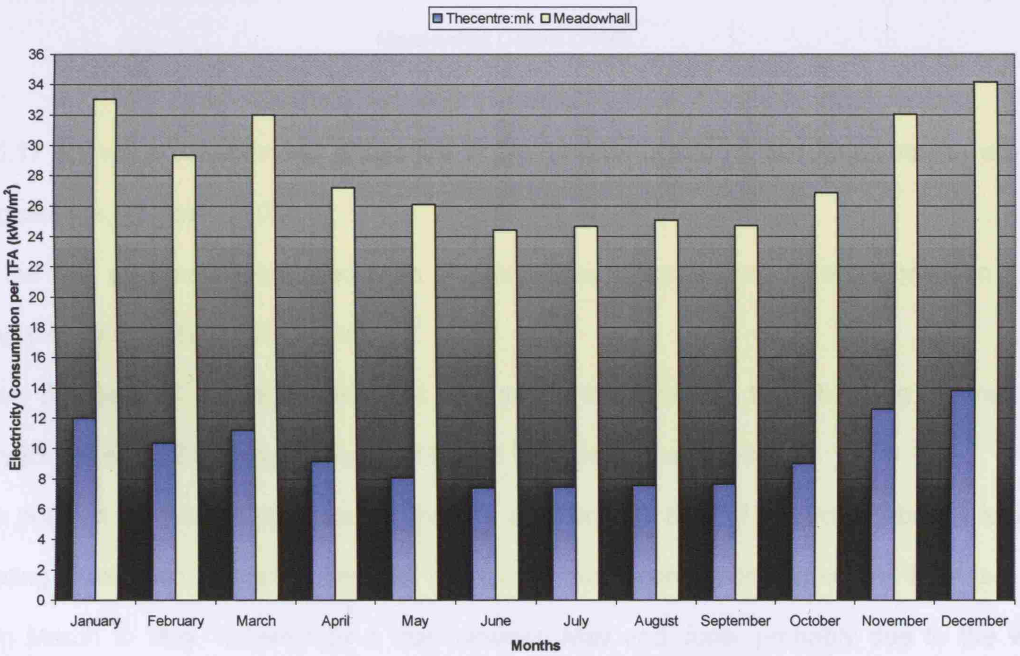

Figure 5.15. Comparison of annual profiles of electricity consumption per TFA in Thecentre:mk and Meadowhall Centre (2005).

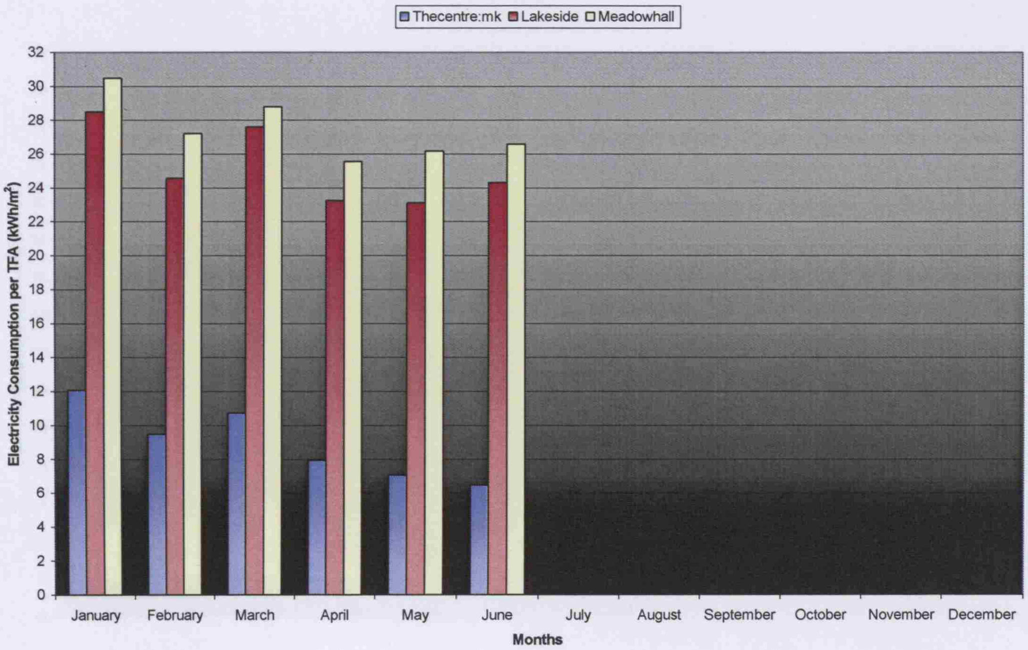

Figure 5.16. Comparison of annual profiles of electricity consumption per TFA in Thecentre:mk, Lakeside Shopping Centre and Meadowhall Centre (2006).

Figure 5.17 shows a considerable difference in the annual profile of gas consumption among the shopping centres, at least in 2006.

In fact, the rate of increase and decrease of gas consumption is very different between Lakeside Shopping Centre and Meadowhall Centre.

Moreover, the peak of usage is shifted of one month between the two shopping centres; it is in February for Lakeside Shopping Centre and March for Meadowhall Centre.

After the peak, in the first shopping centre there is a continuous drop of use from February to June, as less heating is required in warmer periods. Instead, in the second shopping centre there is a drop of use from March to May, followed by a rise between May and June, probably due to the works of refurbishment undertaken.

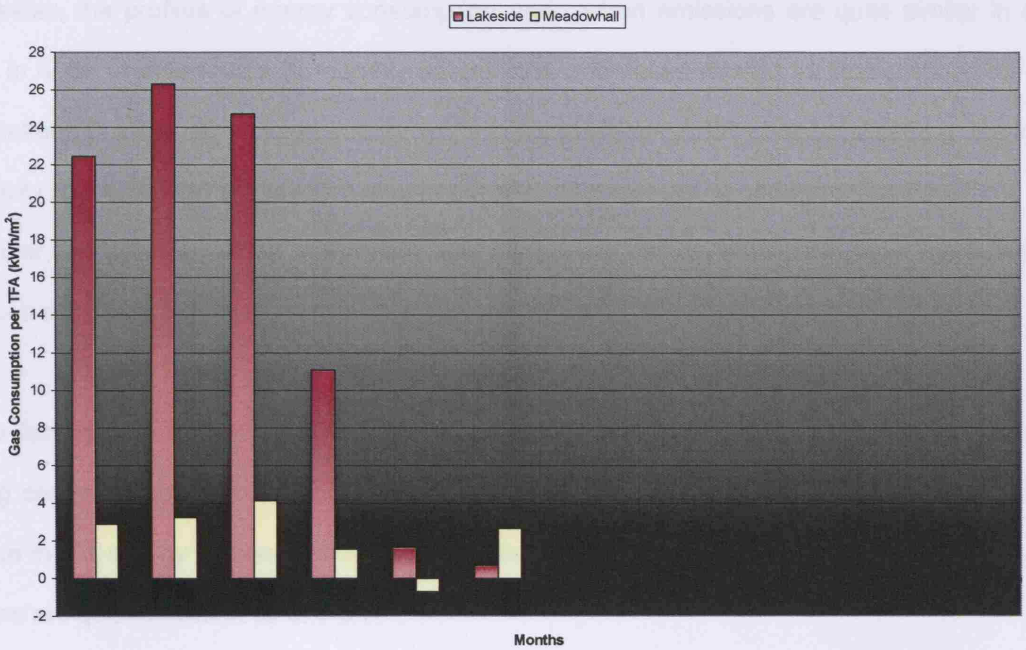

Figure 5.17. Comparison of annual profiles of gas consumption per TFA in Lakeside Shopping Centre and Meadowhall Centre (2006).

The annual profiles of carbon emissions by fuel obviously follow the same trends of their related energy consumptions for both years (see Figures D.4.6 to D.4.8. in Appendix).

5.4. Discussion of analysis results

At the end of this analysis, it is difficult to draw general conclusions about the energy and carbon emissions performance of shopping centres by means of the selected case studies for the following three reasons:

- lack of complete series of data about energy consumption in the same years in two case studies. This affects the possibility of making comparisons between shopping centres;
- lack of sub-meter readings of energy consumption in all case studies. This influences the comparison between shopping centres, as the figures include areas outside the buildings that use a considerable amount of energy (e.g. car parks in Meadowhall Centre);
- underway refurbishment in two case studies. This has created anomalies in the profiles of energy consumption and carbon emissions of those shopping centres.

Nevertheless, the profiles of energy consumption and carbon emissions are quite similar in all case studies, in spite of differences in monthly values and anomalies related to single shopping centres (e.g. variations in the energy usage due to works of refurbishment). Other anomalies (e.g. the increase of electricity use in March) are present in every profile, as they refer to common situations.
In particular, the profiles related to the electricity usage and carbon emissions show more likeness in the various case studies.

The two factors that influence the values of energy consumption and carbon emissions in every shopping centre are the number of occupants and the weather conditions. These do not create great difference in the energy profiles of the case studies as the occupancy pattern and the target internal conditions are quite similar in all of them.
In particular, the number of occupants especially affects the electricity usage, as an increase in occupancy involves an increase in ventilation and/or cooling demand in both summer and winter periods.
The weather conditions also affect the electricity usage for lighting and cooling during all seasons; but it influences both electricity and gas usage for heating only in winter period.

A special mention is required by lighting, which appears to be a strong determinant of the electricity use, even more than cooling. The use of dimming controls, such as photocell controls for the day and occupants controls for the night (e.g. in Thecentre:mk and Meadowhall Centre) seems to produce an effective reduction in electricity usage. Nonetheless, the demand of electricity for lighting during winter period keeps quite high.

For these reasons, electricity is the most used type of energy in every shopping centre, but at the same time the highest source of carbon emissions in each of them.

Chapter 6:

BREAKING DOWN ENERGY USE

6.1. Introduction

After a preliminary audit seeking to establish the quantity of each form of energy used in the shopping centres, it should be possible to produce a breakdown of energy end-uses that corresponds reasonably well with the energy bought from the supplier.

In fact, as seen in Chapter 5, performance indicators give only a broad indication of building efficiency and, therefore, must be treated with caution. It should not be assumed that a building with a "good" performance indicator is, in fact, being operated as efficiently as is possible, or offers no scope for cost-effective savings. Overall performance indicators can mask underlying problems with individual end-uses of energy. Techniques, shown for instance in CIBSE TM22[74], allow a more detailed analysis in terms of end-use consumption (e.g. lighting, fans, etc.) in order to identify more closely where energy problems are occurring within the building. This is a staged approach, requiring more detailed input data at each stage and ultimately provides a comparison of actual end-use consumption with equivalent end-use benchmarks.

As previously pointed out, data from sub-meters are not available and end-use benchmarks do not yet exist for shopping centres.

Therefore, a regression analysis has been carried out as an attempt to determine a breakdown of energy by end-use from data of energy consumption to identify typical sources of inefficiency in shopping centres.

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[74] *Energy assessment and reporting methodology*. CIBSE TM22. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. June 2006.

6.2. Regression analysis

A regression analysis involves developing a performance line equation (i.e. a linear equation of the form: $y = m x + c$). In fact, energy consumption varies with the variation of the external temperature in relation to the internal temperature (Δt), which is usually almost constant in air-conditioned shopping centres during the whole year. So, the difference between the inside and outside air temperatures has a direct influence on heating and cooling loads.

The data useful for this regression analysis are the same used for the analysis of the energy and carbon emissions performance:

- monthly energy consumption data,
- monthly weather data.

The analysis of energy data will show a simple linear relationship. The correlation and base load data obtained from such plot can provide useful information on energy use, particularly relating to control and standing losses.
This technique will be used to determine the energy demand for ventilation and hot water in shopping centres.

The energy requirement of a building at any particular time depends on the state of the heat losses and heat gains at that time.

6.2.1. Heat losses

Assuming steady state conditions[75], the *heat losses* from a building can be classed as:

- *fabric heat loss* (F.H.L.),
- *ventilation heat loss* (V.H.L.).

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[75] "Steady state conditions" means that temperatures inside and outside the building do not change with time and the various flows of heat from the building occur at constant rates. (McMullan R. *Environmental Science in Building.* 5th Edition. Palgrave Macmillan. Basingstoke. 2002. Page 72.

Fabric heat loss from a building is caused by the transmission of heat through the materials of walls, roofs and floors. Assuming steady state conditions, the heat loss for each element can be calculated by the following formula:

$$Q_f = U\,A\,\Delta T$$

where:

Q_f is the rate of fabric heat loss (W);

U is the U-value of the element considered (W/m^2K);

A is the area of that element (m^2);

ΔT is the difference between the inside and outside air temperatures (K).

Ventilation heat loss from a building is caused by the loss of warm air and its replacement by air that is colder and has to be heated. The rate of heat loss by such ventilation or infiltration is given by the following simplified formula:

$$Q_v = 0.33\,N\,V\,\Delta T$$

where:

Q_v is the rate of ventilation heat loss (W);

$0.33 = C_v / 3600$ is a set figure for a set volumetric specific heat capacity of air (W/m^3K)

N is the air infiltration rate for the space considered, i.e. the number of complete air changes per hour (ac/h);

V is the volume of the space (m^3);

ΔT is the difference between the inside and outside air temperatures (K).

6.2.2. Heat gains

The factor affecting *heat gains* are considered under the following categories:

- *solar heat gains* (S.H.G.) from the sun,
- *casual heat gains* (C.H.G.) from occupants, lighting and equipment in the building.

6.2.3. Energy balance

When heat losses and heat gains have been determined it is possible to calculate the extra energy needed to "balance" the losses and the gains and to give a constant temperature. The following is a general expression of balance which is true for summer and winter conditions:

F.H.L. + V.H.L. = S.H.G. + C.H.G. + Energy for heating or cooling

In winter for a building the "useful energy" which needs to be supplied by the heating plant is given by the following expression:

Useful energy = Heat losses – Heat gains

In summer for a building the "useful energy" which needs to be supplied by the cooling plant is given by the following expression:

Useful energy = Heat losses + Heat gains

Therefore, on the whole year, for a building the "useful energy" which needs to be supplied by the heating or cooling plant is given by the following expression:

Useful energy = Heat losses ± Heat gains

Expressing the previous considerations into a formula, the energy balance can be written as:

$$Q = Q_f + Q_v \pm q$$

where:

Q is the useful energy (W);

Q_f is the fabric heat loss (W);

Q_v is the ventilation heat loss (W);

q is the heat gains (W).

Substituting the formula for heat losses, the previous expression becomes:

$$Q = U\,A\,\Delta T + 0.33\,N\,V\,\Delta T \pm q = (U\,A + 0.33\,N\,V)\,\Delta T \pm q$$

Indicating (U A) as rate of F.H.L. (c_f) and (0.33 N V) as rate of V.H.L. (c_v), the previous formula can be written as:

$$Q = (c_f + c_v)\,\Delta t \pm q$$

This expression represents a line equation or linear equation in the form: $y = m\,x \pm c$, where:

- $c_f + c_v$ is the angular coefficient or slope m;
- q is the intercept or constant term c.

In the specific case of the selected shopping centres, "Q" is given by the sum of the useful energy from electricity and the useful energy from gas. The useful energy from electricity coincides with the delivered electricity energy, assuming an efficiency of 100 % for the building service system. The useful energy from gas, instead, is obtained by multiplying the delivered gas energy by the efficiency of the heating system, which is less than 100 %, as all gas is used for space and water heating only.

To determine "ΔT" the mean internal air temperature (t_i) and the mean external air temperature (t_e) are used, as these are more appropriate in the calculation of heat losses.

In the data available from the MET Office[76], the monthly mean external temperatures (t_e) are calculated as the average of monthly minimum and maximum temperatures, obtained in its turn from daily minimum and maximum temperatures averaged on a month, and not as the average of daily mean temperatures, obtained in its turn from hourly temperatures averaged over 24 hours. The second way of calculating monthly mean external temperatures would have been more precise for this purpose.

6.2.4. Plotting of the regression line

Plotting the total useful energy (Q) versus the difference between the inside and outside air temperatures (ΔT) in Excel, a scatterplot is obtained, where each point corresponds to a monthly condition. In the attempt at producing a thermal performance line for a building, a fitted regression line is drawn over the data, performing a linear regression analysis in an Excel chart. The regression line that Excel fits will have an equation of the form y = m x + c, where the slope (m) and the intercept (c) are known (see, for example, Figure 6.1).

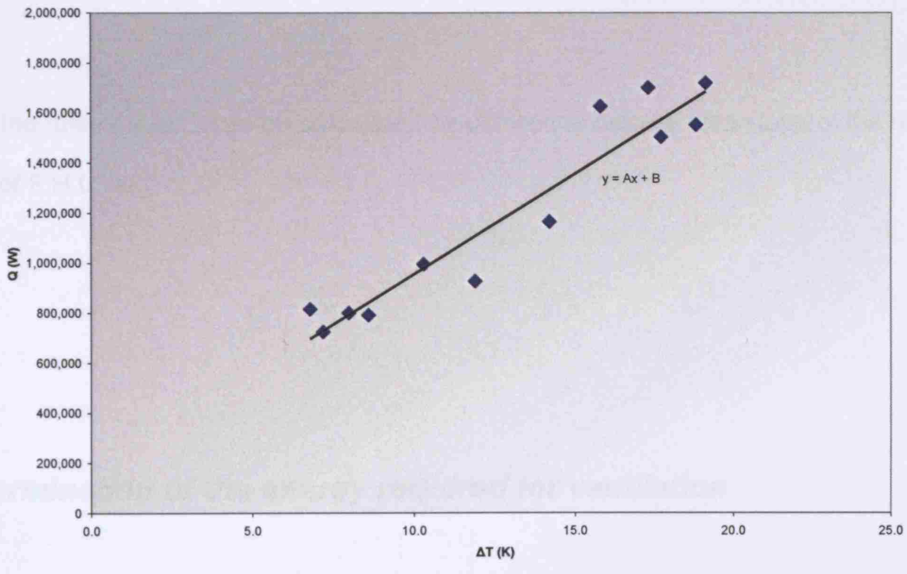


Figure 6.1. Scatter plot of useful energy per hour versus temperature difference.

76 Met Office. http://www.metoffice.com/, accessed August 2006.

The regression linear analysis also shows the residuals (R^2), which are the gaps between the line and the points. The residuals represent the difference between the observed dependent values (y) and the predicted values. So, a positive residual means the building is consuming more energy than it should do and, on the opposite, a negative residual means the building is consuming less energy than it should do.

In addition, the residual, also called coefficient of determination, gives a measure of how much data are explained by the linear relationship and is a value between 0 and 1, with a value of 1 representing 100 % correlation. If the value of R^2 is low (and there are statistical levels that can be worked out), then there is no reliable relationship between energy and temperature difference.

6.2.5. Determination of the rate of F.H.L. and V.H.L.

By the formula for the calculation of the F.H.L. from a whole building, it is possible to determine the rate of F.H.L. as:

$c_f = \sum (U\ A)$

Accordingly, the rate of V.H.L. can be calculated by difference between the slope of the regression line and the rate of F.H.L. as:

$c_v = m - c_f$

6.2.6. Determination of the energy required for ventilation

Then, knowing the rate of V.H.L., it is possible to determine the *air change rate* of the whole building as:

$N = c_v / (0.33\ V)$

The air change rate can be transformed in *volumetric air flow* (in m^3/s) by the equation:

$q_v = (N\ V) / 3600$

Substituting $N\ V = c_v / 0.33$, the volumetric air flow rate can also be expressed as:

$q_v = c_v / (0.33 \times 3600)$

Knowing the volumetric air flow rate, it is possible to determine the *total electrical power required for fans* (in W) as:

$P_e = SPF\ q_v$

where:

SPF is the specific fan power.

According to the Building Regulations Approved Document L2[77], the *specific fan power* (SPF) is the sum of the design total circuit-watts, including all losses through switchgear and controls such as inverters, of all fans that supply air and exhaust it back to outdoors (i.e. the sum of supply and extract fans), divided by the design ventilation rate through the building.

For AC/MV systems in new buildings, the SFP should be no greater than 2.0 W/l/s. For new AC/MV systems in refurbished buildings or where an existing AC/MV system in an existing building is being substantially altered, the SFP should be no greater than 3.0 W/l/s. These SFP values are appropriate to typical spaces ventilated for human occupancy. CIBSE Guide B[78] also suggests that very energy efficient systems can achieve specific fan powers of 1 W/l/s.

Therefore, as no SPF is known from the shopping centres, for the purpose of this calculation an average SPF of 2.0 W/l/s can be assumed.

[77] *Conservation of fuel and power in buildings other than dwellings.* Approved Document L2. Building Regulations 2000. 2002 edition. Department of Transport, Local Government and the Regions (DTLR). The Stationary Office. London. 1st April 2002. Page 24.

[78] *Heating, ventilating, air conditioning and refrigeration.* CIBSE Guide B. Chartered Institution of Building Services Engineers (CIBSE). London. May 2005. Page 3-7.

At this point, the energy required for the ventilation of the building is determined as total electrical power required for fans.

6.2.7. Determination of the energy required for hot water and space heating

To determine the energy required for hot water and space heating, a breakdown of gas consumption is necessary. For this purpose, a regression analysis can be carried out by plotting a performance line using gas consumption and temperature difference (see, for example, Figure 6.2).

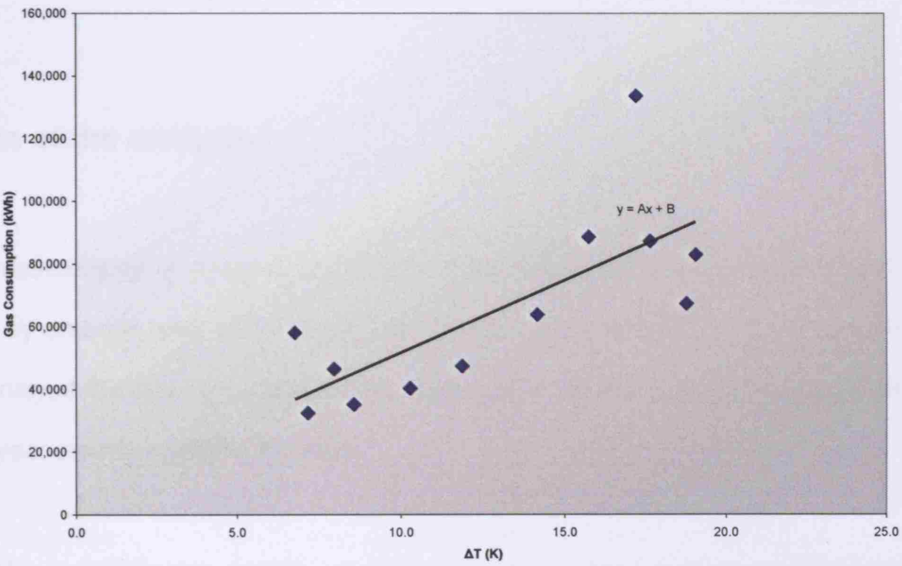


Figure 6.2. Scatter plot of gas consumption versus temperature difference.

The monthly base load gas consumption given by the intercept is the energy required for hot water, as no space heating is provided to the building when $\Delta T = 0$ K.

Then, the energy for space heating can be calculated as difference between the gas consumption and the base load gas consumption.

6.2.8. Determination of the energy required for lighting and (cooling + small power)

The energy required for lighting can be calculated knowing the illuminance from monitoring, if data from sub-meters are not available. However, for the selected case study both kinds of data are unavailable.

The energy required for cooling the building and supplying small power for equipment can be calculated as difference between the electricity consumption and the sum of the energy demand for ventilation and lighting.

6.3. Results of the analysis

To test the methodology of analysis illustrated above and build up a typical breakdown of energy consumption by end-use, one of the three case studies, Meadowhall Centre, is considered. It is not possible to analyse the other two case studies because complete series of energy consumption data for the 2005 year are not available for them.

Two series of calculations are carried out assuming in one case that the energy consumption only refers to the opening time (scenario A) and in the other case that the energy consumption refers to 24 hours (scenario B). In the first situation the energy consumption is overestimated because it is supposed that the same amount of energy is used to operate the shopping centre for the opening time only. In the second situation the energy consumption is underestimated because it is supposed that the same amount of energy is used to operate the shopping centre for 24 hours. The real situation is between the two scenarios. In fact, the energy consumption is continuous on the whole day, but is higher during the opening time and lower during the closing time.

The same temperature difference (ΔT), useful energy and rate of F.H.L. (c_f) are used in both scenarios (see Tables E.1 to E.3 in Appendix).

To determine ΔT it is supposed that the shopping centre is fully air-conditioned and maintains an inside air temperature of 23 °C on the 24 hours, as it is not known whether the internal temperature changes in the closing time.

The useful energy is determined by multiplying the delivered energy by the efficiency of the building services system, as mentioned previously. To calculate the useful energy from gas, it is considered a minimum efficiency of 87 % for the heating system[79].

To determine c_f the following assumptions have been made:

- The volume of the building considered only refers to the common area like the energy consumption data.
- The shops have the same air temperature of the common area. Generally, this does not happen. Each shop, surrounding the common area, usually has its own building services and environmental conditions, but is directly connected to the mall by opened doors during its opening time. Opening times of shops and common area often differ. However, no energy consumption data for the shops are available. Therefore, to simplify the model, the same temperature is assumed for the whole shopping centre and the heat losses of the common area can be thought as balanced by the heat losses from the shops. So, it is supposed that the heat losses from the common area only occur through the roof and the floor.
- The estimated floor area is taken from a publication provided by the centre management office[80].
- The roof area is considered equal to the floor area and glazed for about 50%.
- The U-values for the roof, rooflight and floor are taken from the Building Regulations Approved Document L1 (1990 edition)[81], as the real ones are unknown. This is considered acceptable because the building was opened in 1990. Those Building Regulations require a U-value of 0.45 W/m^2K for the roof and ground floor, while for the rooflight which exceeds 40 % of the roof area they require to use double glazing with low emissivity coating not grater than 0.2 or triple glazing.

[79] From the *Operation and Maintenance Manual* of Meadowhall, provided by the Centre Management.
[80] *British Land Energy Benchmarking Phase 3. Energy Audits.* Ove Arup & Partners Ltd. British Land Carbon Management Programme. 20th April 2006. Page 42.
[81] *Conservation of fuel and power.* Approved Document L1. Building Regulations 1985. 1990 Edition. Department of the Environment and the Welsh Office. Her Majesty's Stationary Office. London. July 1989. Pages 5-7.

In the absence of information regarding U-values for these types of glazing, the same Building Regulations prescribe a U-value of 0.2 W/m^2K.

Considering an estimated height of 16 m, the volume of the building is:

$V = 16{,}700\ m^2 \times 16\ m = 267{,}200\ m^3$

For the calculations in the scenario A and B see Appendices E.5 and E.6 respectively.

For the calculation of the base load gas consumption see Appendix E.7.

6.4. Discussion of the analysis results

The results of the regression analysis are the following:

- in scenario A, air change rate = 0.64 ac/h and energy required for ventilation = 94,713 W;
- in scenario B, air change rate = 0.16 ac/h and energy required for ventilation = 23,888 W;
- base load gas consumption for hot water: - 30,787 kWh.

The attempt to break down the energy consumption by end-use by a regression analysis shows that there are many variables not well determined such as:

- the U-values of the building fabric,
- the SFP of the ventilation system,
- the hours per day during which the different building service systems (heating, ventilation, lighting, etc.) are working,
- the illuminance in the common area.

These are just some of the undetermined variables that make difficult to achieve a reliable energy breakdown by end-use, even by the use of a computational modelling of the building, because it requires too many assumptions.

The regression analysis carried out confirms that the reliability of the results depends on the quality of data. Besides detailed information about the building fabric and services, and pattern of use, as well as sub-meter readings are extremely necessary to break down the energy consumption by end-use and area. For instance, the energy usage of Meadowhall Centre includes the energy for lighting in the car parks, which is probably considerable.

In addition, to obtain better results, the energy consumption of shops and facilities should be known, as there is a continuous exchange of heat losses and gains between common area and retail units. These flows alter the amount of energy required by the common area.

Chapter 7:

MONITORING

7.1. Introduction

As already mentioned in Chapter 3, an energy efficient shopping centre has to provide its occupants with a comfortable internal environment.

Therefore, the monitoring is an essential part of a site energy survey work to assess the internal conditions and indicate the potential for savings, by comparing information obtained by spot check measurements with environmental targets taken from CIBSE Guides.

The monitoring was carried out in two case studies (Thecentre:mk and Lakeside Shopping Centre) at the same time of the occupants' survey to compare the subjective impressions of the interviewees with the objective data of the environmental conditions.

Additional detailed information could be provided by BMS, which is a useful source of measurements. Nevertheless, this information is not available from the selected case studies.

7.2. Collection of data

The environmental conditions in Thecentre:mk and Lakeside Shopping Centre were monitored for about 24 hours in two different periods of July. In particular:

- Thecentre:mk from 11:00 on 8th July to 11:00 on 9th July, 2006;
- Lakeside Shopping Centre from 11:00 on 15th July 2006 to 11:00 on 16th July, 2006.

The first day of monitoring in each shopping centre was always a Saturday and corresponded to the day of the occupants' survey. This day was chosen as representative of the worst case scenario. In fact, in shopping centres Saturday is usually the most crowded day of the week, especially under sale periods as in July; so, in this day the internal conditions are more difficultly kept under control at the target values.

The data were recorded every 12 minutes, to get 5 records per each hour. This interval is considered suitable to have enough information on the variations of the parameters in the time, but not too much information to be overwhelmed by the same.

The environmental parameters were recorded by common portable instruments, such as HOBO data loggers[82]and CO_2 sensors[83].
The instruments were located in various strategic points of the shopping centres, considered representative of the environmental conditions related to different parts of the common area. In fact, the monitoring, as well as the whole study, aims to assess energy efficiency only in the landlord's area.
External data were also recorded during the interviews.

In Thecentre:mk the monitoring stations were located as follows (see Figure 7.1):

- Spot no. 1, in the Silbury Arcade, near the customer services desk. This station provided data of the area where the occupants' survey was undertaken. The area is three levels high and received natural lighting from a full glazing at the third level on the internal side, toward the Midsummer Boulevard, and at both second and third level on the others.
- Spot no. 2, in the Queens Court. This station provided data of the external conditions.
- Spot no. 3, in the Crown Walk. This station provided data of one of the main cross-galleries, characterized by one level height and fully artificial lighting.
- Spot no. 4, in Midsummer Arcade, near the lottery kiosk. This station provided data of the other main gallery, similar to Silbury Arcade but with an opposite orientation.
- Spot no. 5, in Middleton Hall. This station provided data of the events arena, which is three levels high and receives natural lighting from a full glazing at the second and third level on the sides of the arcades, toward Silbury Boulevard and Midsummer Boulevard.

[82] Models: HOBO TEMP, RH, LI, EXT © 1996 ONSET and HOBO TEMP, RH, 2X EXT © 1999 ONSET.
[83] Model: Telaire© 7001 Monitor. GE Sensing.

In Lakeside Shopping Centre the monitoring stations were located as follows (see Figure 7.2):

- Spot no. 1, at the first level, in the main atrium. This station provided data of the area where the occupants' survey was undertaken. The area is three levels high and received natural lighting from a glazed dome.
- Spot no. 2, at the second level, outside the building, near Primark store. This station provided data of the external conditions.
- Spot no. 3, at the first level, between the man atrium and the adjacent escalators. This station had to provide data of one of the main galleries, characterized by one level height, air and natural lighting from the glazed roof of the third floor, and artificial lighting from the perimetric area, but it was stolen.
- Spot no. 4, at the first level, near Caffè Alba. This station provided data of another typical atrium, similar to the main one but taken up by escalators.
- Spot no. 5, at the second level, near the information desk. This station provided data of the same atrium where is located the spot no. 4, but at a higher level.
- Spot no. 6, at the third level, between the lifts and the escalators. This station provided data of the highest level, which is characterized by natural lighting from the glazed roof.

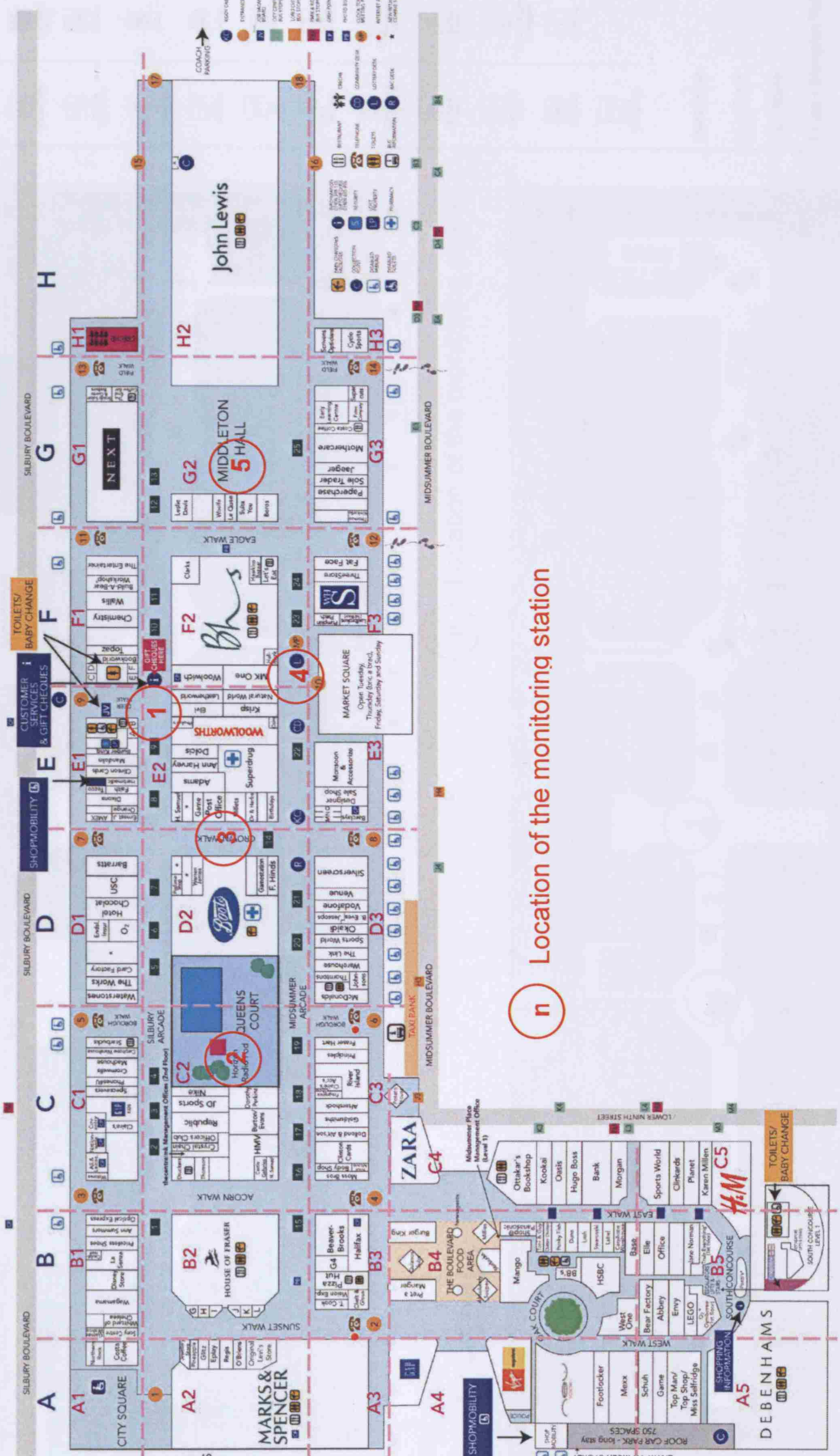
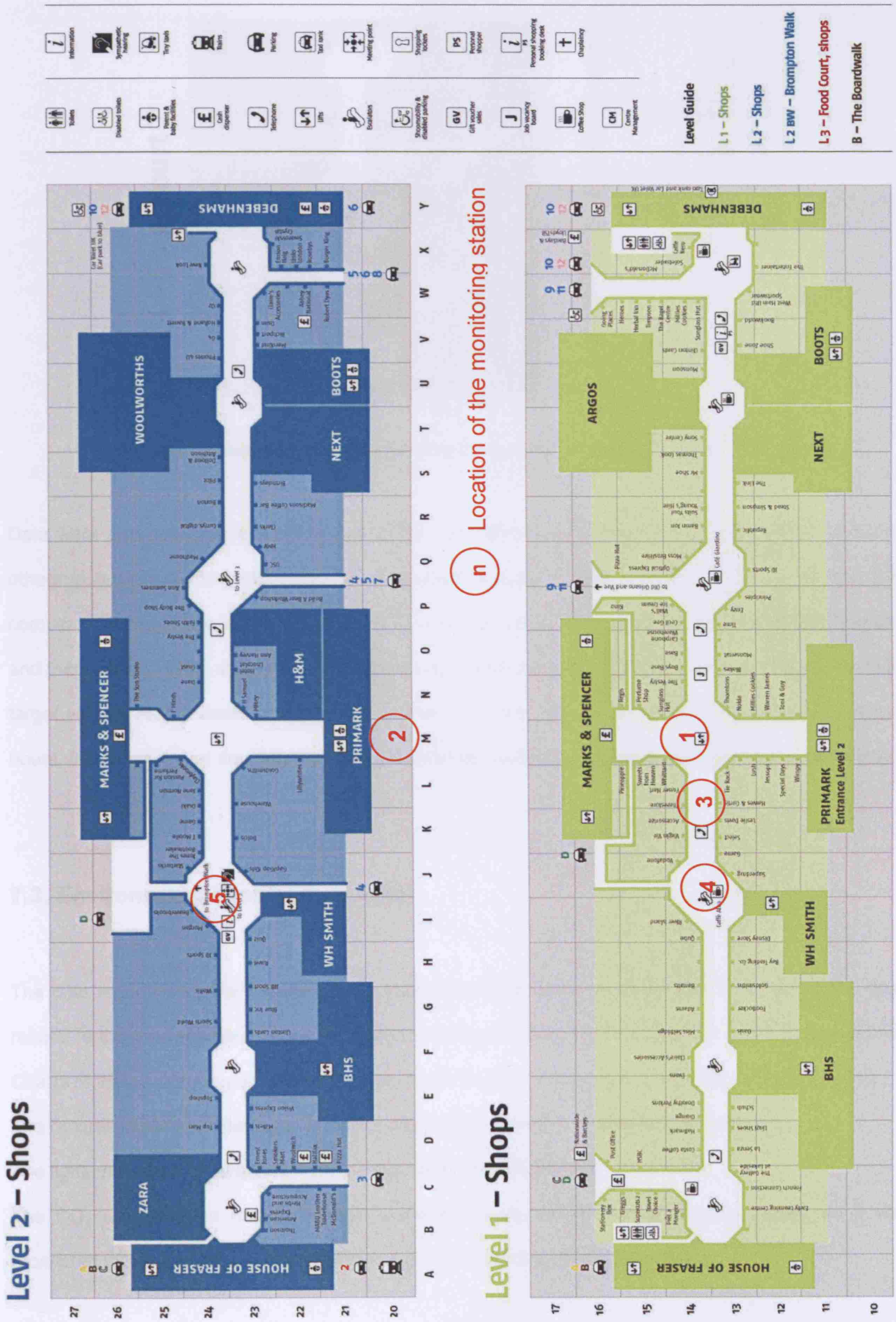


Figure 7.1. Map with the location of the monitoring stations in Thecentre:mk.


Level 2 – Shops
Level 1 – Shops
n Location of the monitoring station
Level Guide
L1 – Shops
L2 – Shops
L2 BW – Brompton Walk
L3 – Food Court, shops
B – The Boardwalk
HOUSE OF FRASER
ZARA
BHS
WH SMITH
PRIMARK
MARKS & SPENCER
H&M
NEXT
BOOTS
WOOLWORTHS
DEBENHAMS
ARGOS
PRIMARK Entrance Level 2

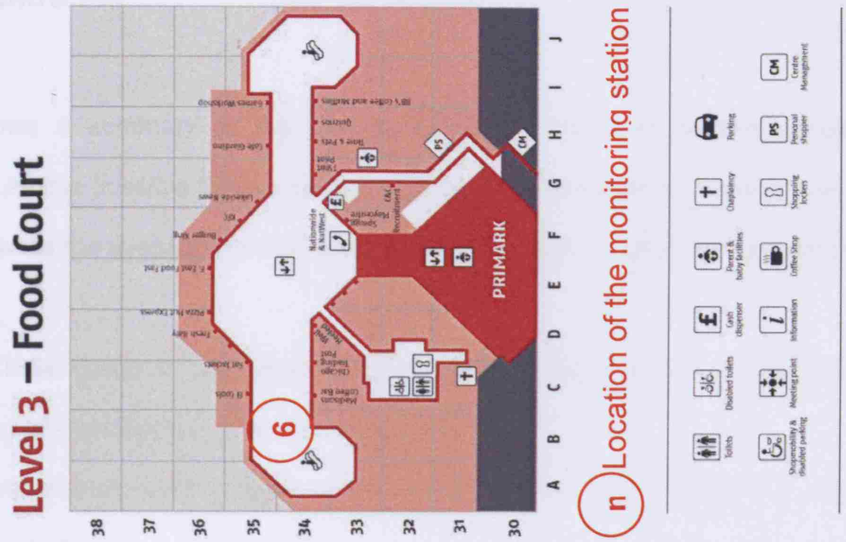


Figure 7.2. Maps with the location of the monitoring stations in Lakeside Shopping Centre.

Data were also collected in some shops of the selected case studies. These shops differ from each others in business, size, and both level and orientation of location. The aim of these records is to compare the conditions inside the shops with those of the common area, as the two types of spaces and their related HVAC systems are managed separately and often the plants are not set at the same target values. As the doors of the retails and services are opened on the malls during their opening hours, the conditions of the common area are affected by those of the adjacent shops and vice versa.

7.3. Environmental analysis of data

The data recorded by the HOBOs were downloaded into Excel spreadsheets to be analysed. Data related to the area selected for the occupant's survey are attached in Tables F.1 and F.2 in Appendix. Charts of the environmental parameters during the occupant's survey are attached in Appendix F.3.

The records include temperature, humidity, illuminance and CO_2 concentration in the air.

The lighting intensity is available only for the inside of the buildings.

The CO_2 concentration is only related to the area selected for the occupant's survey; so it was monitored in the spot no.1 in both Thecentre:mk and Lakeside Shopping Centre.

The data gathered from individual sites are analysed separately in the following sections.

7.3.1. Thecentre:mk

Table 7.1 shows a summary of the environmental conditions during the occupants' survey in Thecentre:mk. As it is possible to see, the average internal temperature is lower than the external one of about 2 °C, while the average internal relative humidity (RH) is higher than the external one of about 3 %.

According to CIBSE Guide A[84], the recommended summer operative temperature range for shopping malls, assuming air-conditioned buildings, is 21-25 °C[85].

The internal temperature satisfied these comfort criteria, even though tends to be slightly higher than the suggested values.

In addition, the internal temperature and RH are quite stable (T = 23.24 – 25.56 °C; RH = 33.9 – 39.5 %) (see Figures F.3.1 and F.3.2 in Appendix).

Table 7.1. Summary of the environmental conditions during the occupants' survey in Thecentre:mk.

Parameter	Unit	Average	Minimum	Maximum
Internal Temperature	°C	24.80	23.24	25.56
External Temperature	°C	26.43	21.71	34.43
Internal RH	%	35.6	33.9	39.5
External RH	%	32.2	23.7	42.9
Internal Illuminance	lum/m^2	28	13	43
Internal CO_2 Concentration	ppm	656	542	767

In particular, Figure 7.3 shows that the internal conditions, in terms of temperature and absolute humidity, satisfy the (ASHRAE) comfort criteria most of the time, except in the central opening hours, when the internal temperature reaches the maximum of 25.56 °C and the absolute humidity varies between 6.8 and 6.9 g/kg. This happens between 14:36 and 16:12, when the external temperature and humidity are quite high, but lower than the internal ones. The reason of higher internal temperature and humidity is probably the high level of occupancy in the shopping centre and solar radiations in the monitored area.

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[84] *Environmental design.* CIBSE Guide A. 7th edition. Chartered Institution of Building Services Engineers (CIBSE). London, January 2006. Pages 1-7 – 1-10.

[85] Based on CIBSE Guide A, the operative temperature range corresponds to a predicted mean vote (PMV) of ± 0.5 and assumes a clothing insulation of 0.65 clo (corresponding to 0.101 m^2°C/W)) and a metabolic rate of 1.8 met (corresponding to 104.76 W/m^2). On the basis of BS EN ISO 7730:2005, these values of clothing insulation and metabolic rate corresponds in turn to a typical combination of summer garments and a standing, light to medium activity typical of shoppers and shop assistants.

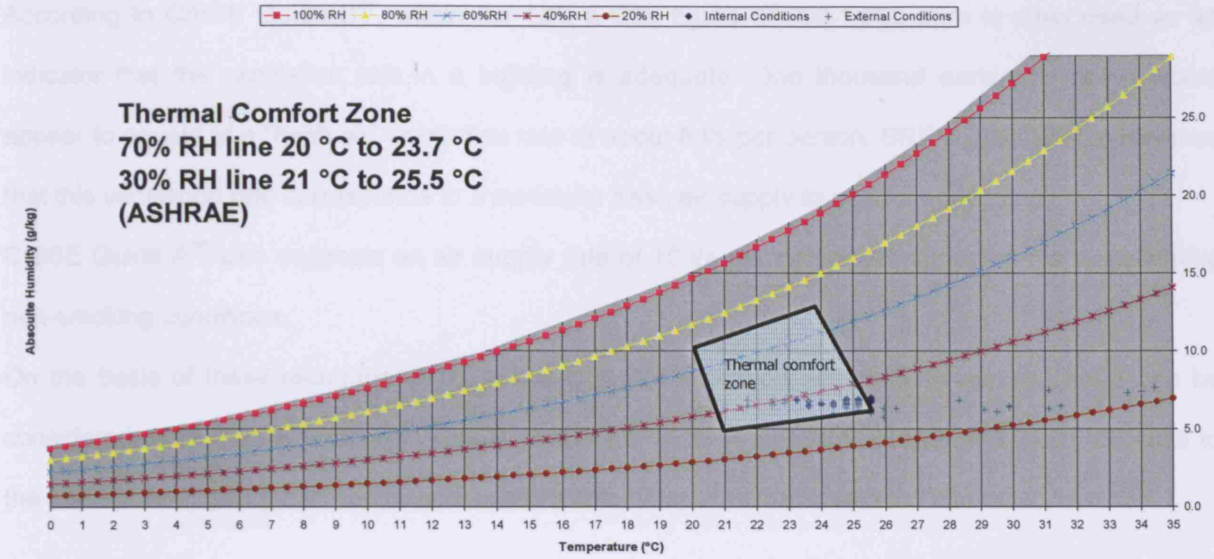

Figure 7.3. Psychrometric chart of the environmental conditions during the occupants' survey in Thecentre:mk.

Figure 7.4 shows that the internal CO_2 concentration increases from 581 ppm at 11:00 to 767 ppm at 14:36 and then decreases to 542 ppm at 17:48.

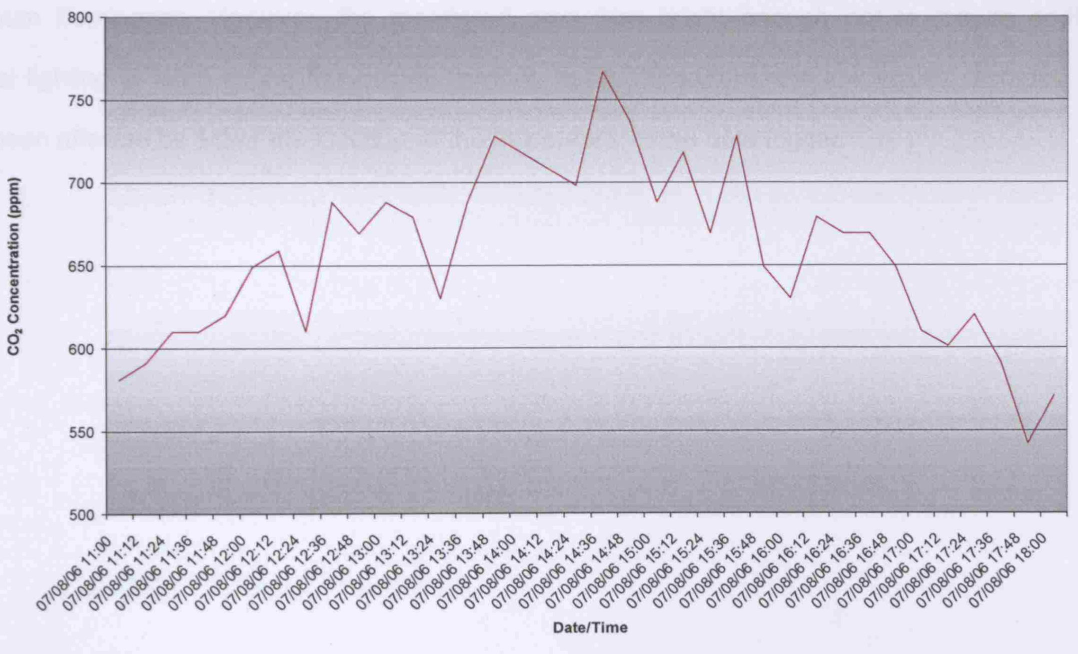

Figure 7.4. Profile of the internal CO_2 concentration during the occupants' survey in Thecentre:mk.

In addition, Table 7.1 shows that the average CO_2 concentration inside the building is 656 ppm.

According to CIBSE Guide B[86], within the UK, a CO_2 figure of 800-1,000 ppm is often used as an indicator that the ventilation rate in a building is adequate. One thousand parts per million would appear to equate to a "fresh air" ventilation rate of about 8 l/s per person. BRE Digest 399[87] underlines that this ventilation rate corresponds to a minimum fresh air supply to control body odour.

CIBSE Guide A[88] also suggests an air supply rate of 10 l/s per person for shopping malls, assuming non-smoking conditions.

On the basis of these recommendations, the CO_2 concentration within the shopping centre can be considered more than satisfactory. This is due not only to an efficient ventilation system, but also to the non-smoking policy carried out across the whole centre, as mentioned in Chapter 4.

Figure 7.5 and Table 7.1 show that the illuminance varies between a minimum of 13 lux and a maximum of 43 lux and has an average of 28 lux. This constant fluctuation in the profile of the illuminance is probably due to the changes in the sky clearness and position of the sun as the internal lighting is completely natural in the monitored area.

CIBSE Guide A[89] recommends a maintained illuminance of 50-300 lux, which is higher than the maximum illuminance. However, the monitored area was bright enough not to require additional artificial lighting at least during the central working hours. Therefore, the low values recorded might have been affected by either the location or the inaccuracy of the data logger.

[86] *Heating, ventilating, air conditioning and refrigeration*. CIBSE Guide B. Chartered Institution of Building Services Engineers (CIBSE). London. May 2005. Page 2-15.

[87] *Natural ventilation in non-domestic buildings*. BRE Digest 399. Building Research Establishment (BRE). Garston. October 1994. Page 2.

[88] *Environmental design*. CIBSE Guide A. 7th edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2006. Page 1-9.

[89] *Environmental design*. CIBSE Guide A. 7th edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2006. Page 1-9.

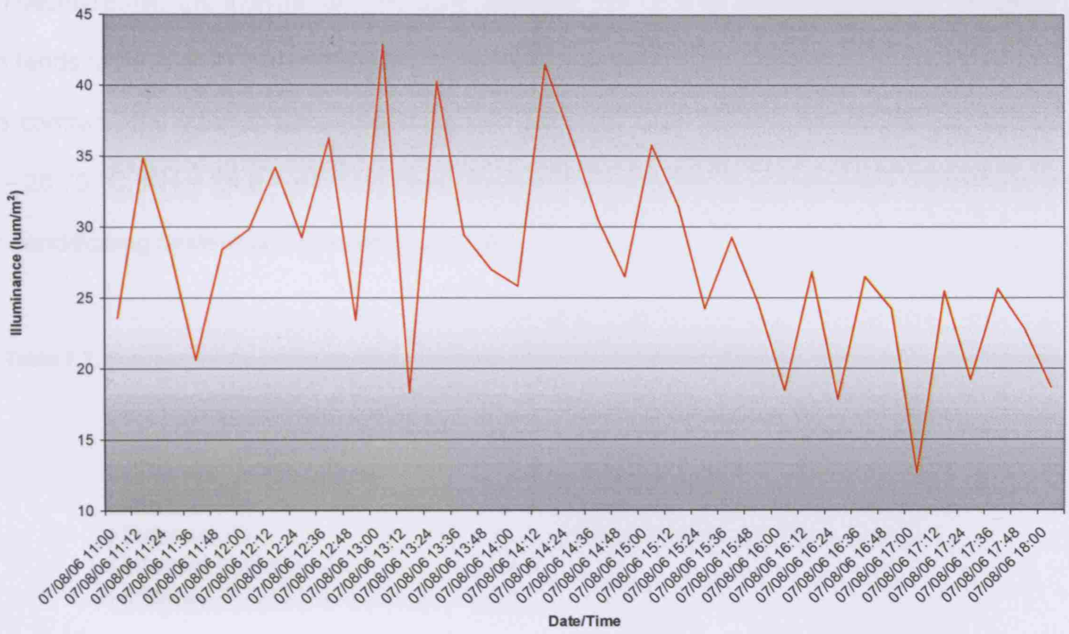

Figure 7.5. Profile of the internal illuminance during the occupants' survey in Thecentre:mk.

Comparing the environmental conditions of the area selected for the occupants' survey with those of the other monitored areas (see Figures F.3.3 and F.3.4 in Appendix), the temperatures in the Crown Walk and in the Middleton Hall are quite stable and satisfactory (23.49 °C and 23.74 °C on average respectively). In addition, they are lower than the temperature in the Silbury Arcade of about 1 °C on average. This situation is due to lower occupancy level and illuminance. The temperature in the Midsummer Arcade (26.43 °C on average) is less stable and higher than that in the Silbury Arcade of about 2 °C on average. The reason of this is may be a slightly higher occupancy and definitely a higher illuminance. In fact, the Midsummer Arcade has mainly a south-east exposition to solar radiations, while the Silbury Arcade mainly a north-west exposition.

7.3.2. Lakeside Shopping Centre

Table 7.2 shows a summary of the environmental conditions during the occupants' survey in Lakeside Shopping Centre. As it is possible to see, the average internal temperature is higher than the external one of less than 1 °C, while the average internal relative humidity (RH) is lower than the external one of about 7 %.

As in Thecentre:mk, the internal temperature satisfied the comfort criteria of CIBSE Guide A[90], even though tends to be slightly higher than the suggested values.

On the contrary, the internal temperature and RH are not very stable and have large variations (T = 22.09 – 28.70 °C; RH = 24.8 – 41.7 %) (see Figures F.3.5 and F.3.6 in Appendix). Therefore, probably the air-conditioning system is not working properly.

Table 7.2. Summary of the environmental conditions during the occupants' survey in Lakeside Shopping Centre.

Parameter	Unit	Average	Minimum	Maximum
Internal Temperature	°C	24.91	22.09	28.70
External Temperature	°C	24.11	20.19	34.43
Internal RH	%	32.7	24.8	41.7
External RH	%	39.3	24.0	49.5
Internal Illuminance	lum/m^2	24	3	59
Internal CO_2 Concentration	ppm	677	532	747

In particular, Figure 7.6 shows that the internal conditions, in terms of temperature and absolute humidity, satisfy the (ASHRAE) comfort criteria most of the time, except in the central opening hours, when the internal temperature reaches the maximum of 28.70 °C and the absolute humidity varies between 5.5 and 6.4 g/kg. This happens between 13:24 and 16:24, when the external temperature is lower than the internal one and the external humidity is higher than the internal one. As in Thecentre:mk, the reason of the higher internal temperature is probably the high level of occupancy in the shopping centre and solar radiation in the monitored area. But this assumption does not explain the lower internal humidity.

[90] *Environmental design.* CIBSE Guide A. 7th edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2006. Pages 1-7 – 1-10.

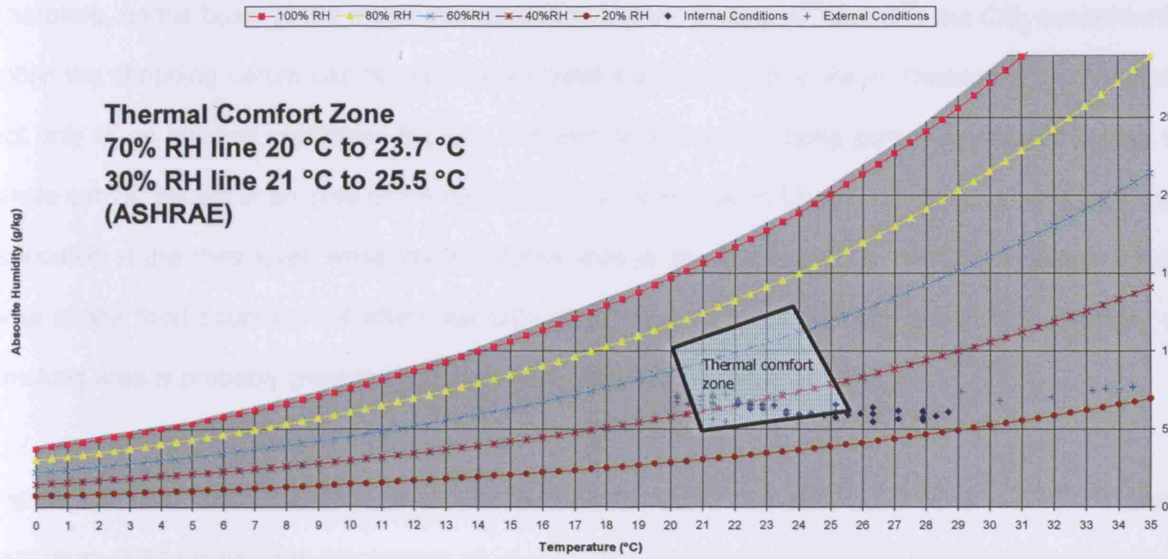

Figure 7.6. Psychrometric chart of the environmental conditions during the occupants' survey in Lakeside Shopping Centre.

Figure 7.7 shows that the internal CO_2 concentration increases from a minimum of 532 ppm at 11:00 to a maximum of 747 ppm at 15:36-15:48 and then decreases again, similarly to Thecentre:mk.

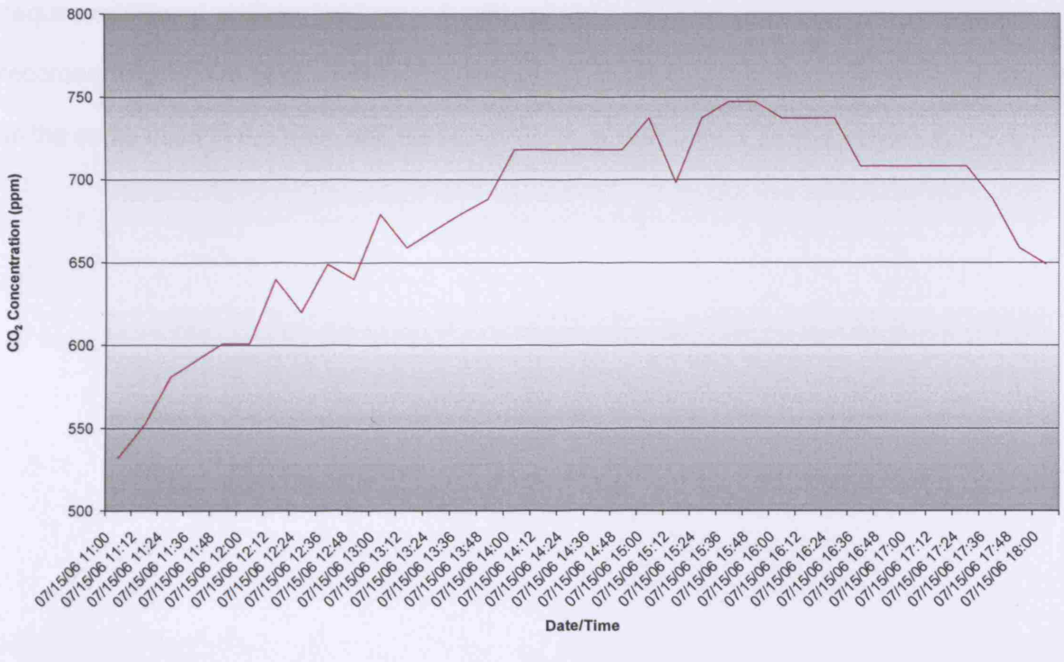

Figure 7.7. Profile of the internal CO_2 concentration during the occupants' survey in Lakeside Shopping Centre.

In addition, Table 7.2 shows that the average CO_2 concentration inside the building is 677 ppm.

Therefore, on the basis of the recommendations of CIBSE Guides A[91] and B[92], the CO_2 concentration within the shopping centre can be considered more than satisfactory. As in Thecentre:mk, this is due not only to an efficient ventilation system, but also to the non-smoking policy carried out across the whole centre, except in an area of the food court, as mentioned in Chapter 4. However, the food court is located at the third level, while the monitored area at the first level. So, the CO_2 emissions in the area of the food court do not affect the CO_2 concentration in the monitored area. In addition, the smoking area is probably provided with a proper ventilation system.

Figure 7.8 and Table 7.2 show that the illuminance varies between a minimum of 3 lux and a maximum of 59 lux and has an average of 24 lux. This particular shape of the profile of the illuminance is probably due to the changes in the sky clearness and position of the sun as the internal lighting is completely natural in the monitored area, as well as to a probable involuntary shadow on the data logger.

The recommended maintained illuminance in CIBSE Guide A[93] is higher than the average illuminance most of the time. However, almost similarly to Thecentre:mk, the monitored area was bright enough not to require additional artificial lighting at least during the central opening hours. Therefore, the low value recorded might have been affected by either the location or the inaccuracy of the data logger, that was the same used in the area selected for the occupants' survey of Thecentre:mk.

[91] *Environmental design.* CIBSE Guide A. 7th edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2006. Page 1-9.
[92] *Heating, ventilating, air conditioning and refrigeration.* CIBSE Guide B. Chartered Institution of Building Services Engineers (CIBSE). London. May 2005. Page 2-15.
[93] *Environmental design.* CIBSE Guide A. 7th edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2006. Page 1-9.

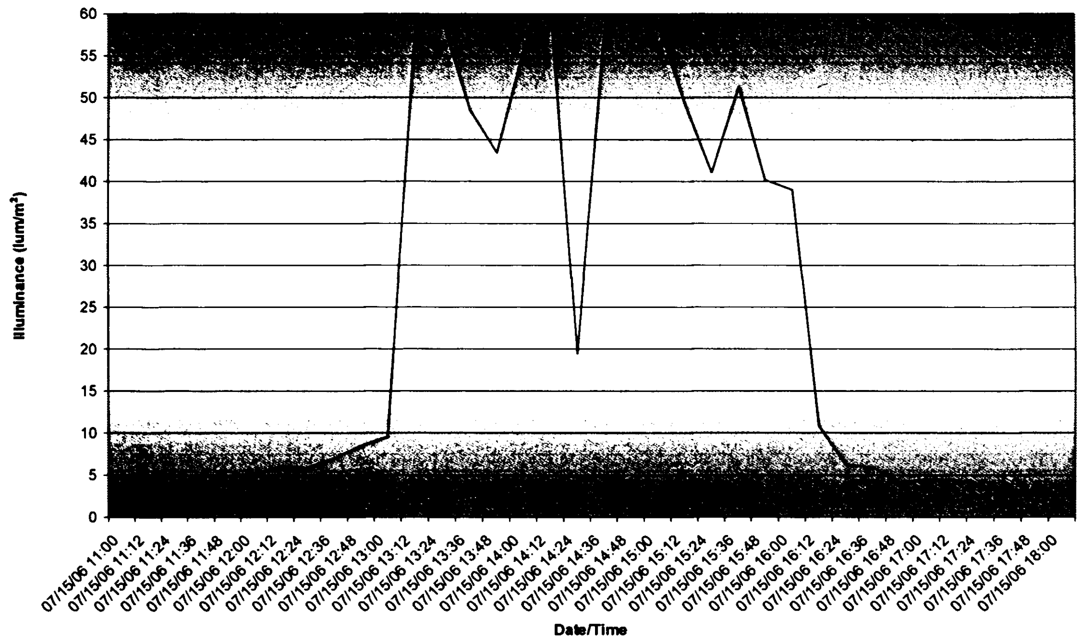

Figure 7.8. Profile of the internal illuminance during the occupants' survey in Lakeside Shopping Centre.

Comparing the environmental conditions of the area selected for the occupants' survey with those of the other monitored areas (see Figures F.3.7 and F.3.8 in Appendix), the temperatures in the other areas increase with the increasing floor level of about 1 °C. This situation is due to a higher illuminance with the increasing floor level, as more natural lighting is driven on the surfaces at heights closer to the rooflights. However, if this clearly appears for the station at the third level, it does not for the other stations, probably for shadows involuntary created by the structure of the building on the data loggers. In fact, the illuminance of the different areas increases on average with the floor level, but has always a drop in a time of the day. Because of shadowing, the illuminance in the surveyed area is still higher than that in the adjacent monitored area on the same floor and the area at the second level.

7.4. Discussion of analysis results

Comparing the results of the monitoring in the two shopping centres, it is possible to highlight some common features.

Both case studies (especially Thecentre:mk) show a satisfactory control of the internal temperature, which may be due to a correct use of the HVAC system; the latter is probably provided with temperature sensors.
However, the internal temperature is slightly affected by the occupancy and sunlight level. In fact, the increase of both factors tends to produce an increase in the internal temperature. In particular, the solar radiations deeply affect the internal temperature, as both buildings have large glazed surfaces: Thecentre:mk on the upper part of the external walls and Lakeside Shopping Centre on the roof.
In addition, Thecentre:mk shows a quite homogeneous distribution of the temperature in the common area, at least at the occupants height, while Lakeside Shopping Centre a temperature stratification, increasing with the floor level.

On the contrary, both case studies (especially Lakeside Shopping Centre) show a moderate control of the internal humidity, which fluctuates with the external humidity and assumes values similar to it. In other words, the internal humidity depends on the external humidity, probably because there is not a specific monitoring and control system for it.

Both case studies show a good control on CO_2 concentration, which may be due to a correct use of the ventilation system and application of a non-smoking policy. Moreover, the ventilation system is probably provided with CO_2 sensors.

Both case studies show a considerable variation of the internal illuminance due to at least three different factors: exposure of the area to natural or artificial lighting; orientation of the area to the solar radiations; changes in the sunlight level during the day.
They also show low values of the internal illuminance, which however may be due to inaccuracies in the monitoring.

Finally, in both case studies the environmental conditions of the common areas differ from those of the shops, as the two types of spaces and their related HVAC systems are managed separately and the plants are not set at the same target value. By the data analysis, it was not possible to outline a general profile of the various parameters monitored valid for all the shops or some categories of them.

Chapter 8:

OCCUPANTS' SURVEY

8.1. Introduction

As already mentioned in Chapter 3, an energy efficient shopping centre has to provide its occupants with a comfortable internal environment.
Therefore, an occupants' survey was carried out in two case studies (Thecentre:mk and Lakeside Shopping Centre) to determine the occupants' expectation for comfort and awareness of energy efficiency in shopping centres.

The occupants' survey was conducted at the same time of the monitoring and in two of the same areas monitored to compare the objective data of the environmental conditions with the subjective impressions of the interviewees.

8.2. Collection of data

8.2.1. Selection of interviewees

Interviewees are selected between shoppers and tenants, according to the subdivision of energy consumption between landlords' and tenants' areas.
In most cases, the questionnaire of tenants was directed to the staff that usually spends more time in the shops, especially in department stores, large retailers and supermarkets, than the tenants and so is able to give a more precise appraisal of the environmental conditions in the shops.

8.2.2. Content of the survey forms

The survey forms are partially based on the Questionnaire for Post-occupancy Building Evaluation[94] and an occupant survey questionnaire included in a BRE publication[95].

The survey form for shoppers is divided into 6 sections (see Appendix G.1), while that for tenants into 8 sections (see Appendix G.2).

Both survey forms deal with *background* information (range of age, gender, length of the shopping trip in the building or working period in the shop at the specific time of the survey, and length of a typical shopping trip in the building); *thermal comfort* (temperature, air movement and air quality); *lighting* (quality of the natural and artificial lighting, and amount of glare or uncomfortable brightness from both sun and sky as well as lights); *overall comfort* in the common area or shop, and in the whole building in general; *improvement* on the environmental factors (temperature, air movement, air quality, natural lighting and artificial lighting); *shopping conditions* in the building or shop.
In addition, the survey form for tenants deals with *personal control* over heating, cooling, ventilation, natural lighting and artificial lighting; interest in the *energy issue*; *working conditions* in the shop.

All the questions to shoppers refer to the specific part of the common area where the survey is carried out and the specific time in which the survey is undertaken, unless otherwise stated.
All the questions to tenants refer to the specific shop where they are interviewed and the specific time in which the survey is undertaken, unless otherwise stated.

The purpose of having same questions for shoppers and tenants is to compare the two areas of the building: landlords' and tenants'. In fact, the management of the two areas and their HVAC systems are separated.

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[94] Questionnaire for Post-occupancy Building Evaluation. Building Use Studies (BUS) Ltd. Copyright © 1985-2006.
[95] Laing A., Duffy F., Jaunzens D., Willis S. *New Environments for Working. The re-design of offices and environmental systems for new ways of working.* Published by Construction Research Communications Ltd by permission of Building Research Establishment (BRE). E & FN Spon Press. London 1998.

8.2.3. Completion of the survey forms

172 survey forms were completed as follows:

- 84 in Thecentre:mk on Saturday 8th July 2006;
- 88 in Lakeside Shopping Centre on Saturday 15th July 2006.

The day in which the survey was carried out was always a Saturday. This day was chosen as representative of the worst case scenario. In fact, in shopping centres Saturday is usually the most crowded day of the week, especially under sales period, as in July; so, in this day the internal conditions are more difficultly kept under control at the target values.

In both shopping centres 50 questionnaires were filled by shoppers, half in the morning from 11:00 to 13:00 and half in the afternoon from 15:00 to 17:00, and one each 5 minutes.

As regards the questionnaires of tenants, 34 were filled in Thecentre:mk and 38 in Lakeside Shopping Centre, in both cases half in the morning and half in the afternoon.

The surveys of shoppers and tenants were carried out at the same time to assure comparable results.

8.3. Analysis of responses

The data from the completed forms were decoded by the use of questionnaire for coding purpose (see Appendices G.3 and G.4) and analysed in Excel, using pivot tables and charts (see Appendices G.5 and G.6).

The results of the surveys of shoppers and tenants are analysed in Appendices G.7 and G.8 respectively.

8.4. Discussion of analysis results

8.4.1. The results of shoppers' survey

Most of the shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre are 25 to 44 years old and usually spend 2 to 4 hours (i.e. about half day, considering a day made up of 8 working hours) in the buildings on a typical shopping trip. In particular, the visitors that stay longer in the shopping centres are female (see Figure 8.1).

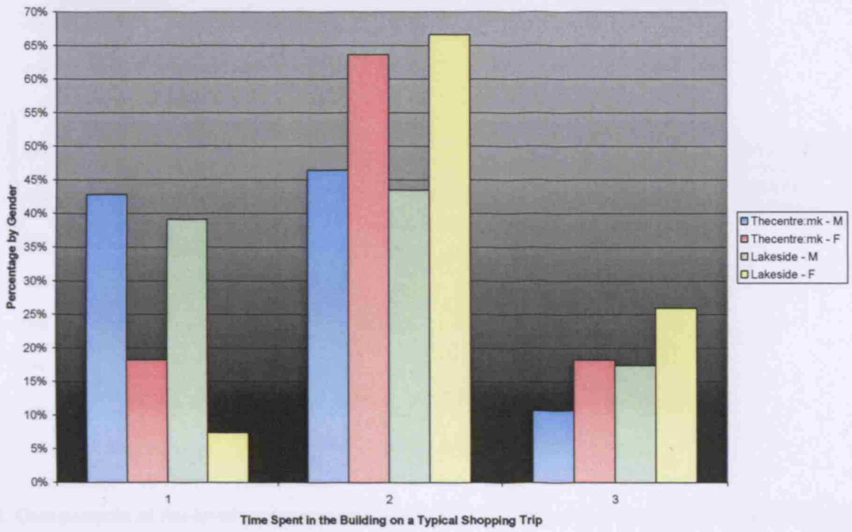

Figure 8.1. Comparison of the time spent in the building on a typical shopping trip by gender.

(Scale: 1 = 0-2 hours, 2 = 2-4 hours, 3 = 4-8 hours)

Customers would not stay longer in the buildings if the environmental conditions were perfect (see Figure G.7.16). In particular, the majority of these people are male. Therefore, the internal conditions do not seem to be a priority for visitors during shopping. However, the choice of a shopping centre instead of another might be affected by their concern about the environmental conditions in the buildings.

8.4.2. The results of tenants' survey

Most of the shop assistants interviewed in Thecentre:mk and Lakeside Shopping Centre are 18 to 24 years old and not particularly concerned in saving energy in the shops, especially in Lakeside Shopping Centre. In particular, the people working in the shopping centres that are less interested in energy issues are male (see Figure 8.2). The indifference of shop assistants to the energy issue may be due to their non-involvement in the management of the shops.

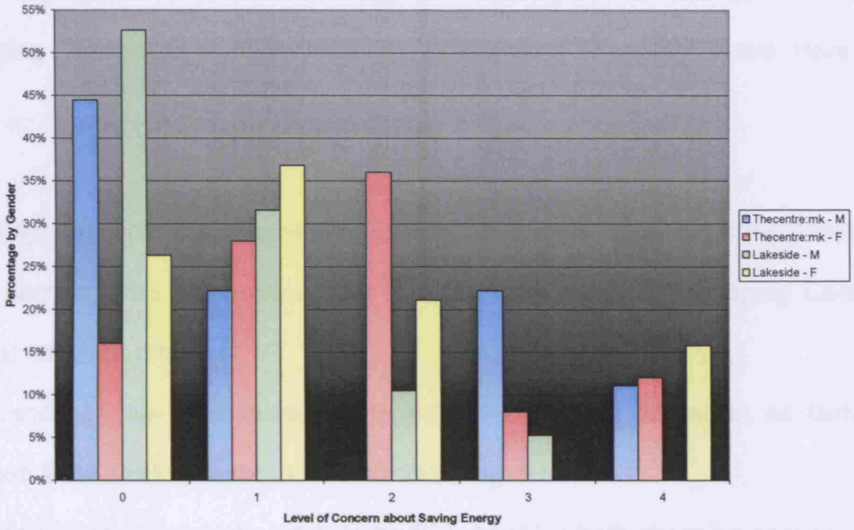

Figure 8.2. Comparison of the level of concern the tenants have about saving energy in their shops by gender.

(Scale: 0 = Not at all, 1 = Slightly, 2 = Moderately, 3 = Very, 4 = Fully)

8.4.3. Comparison of the results of shoppers' and tenants' surveys

Comparing the results of shoppers' and tenants' surveys to stress the eventual differences between common area's and shop's environments, it is important to bear in mind a limitation: people that rated the common area are not the same one that rated the shops. Moreover, people that rated the two types of spaces differ in the composition by number, age and gender. These differences may deeply affect the results especially in terms of comfort.

The comparison will deal with the three main issues, related to the perception of comfort, that have been covered in both types of questionnaires: thermal comfort, lighting and overall comfort.

As regards the *thermal comfort*, the temperature, air movement and air quality are generally considered satisfactory in both shopping centres, with the exception of the shops in Thecentre:mk, where the temperature is rated slightly cool.

Observing the tendency to shift from the neutrality, the ambient temperature is perceived as low in the whole Lakeside Shopping Centre, while differs between common area and shops in Thecentre:mk. Here people feel warmer in the common area and cooler in the shops.

The air movement generally tends to be fairly still in both shopping centres and improvement are suggested.

The air quality is tendentially considered fresh in Thecentre:mk as well as the common area of Lakeside Shopping Centre and stuffy in the shops of Lakeside Shopping Centre. Here improvements are suggested.

In regard to the *lighting*, both the natural and artificial lighting are generally considered satisfactory in both shopping centres, with the exception of the shops in Lakeside Shopping Centre, where the natural lighting is rated too dim.

Looking at the shifting from the neutrality, the natural lighting is perceived as fairly bright in the common area and fairly dim in the shops of both shopping centres.

Instead, the artificial lighting generally tends to be fairly bright in both shopping centres.

No glare from both sun and sky, and lights is generally perceived in both shopping centres, except in the shops of Lakeside Shopping Centre, where people have glare from lights occasionally.

Glare from sun and sky tends to cause discomfort more often in the common area of Lakeside and in the shops of Thecentre:mk. Glare from lights tends to be a problem more often in Lakeside Shopping Centre than in Thecentre:mk. On the whole, Lakeside Shopping Centre seems to have more often problems of glare than Thecentre:mk, especially in the common area.

With regard to the *overall comfort* in general, people feel satisfactory in both shopping centres.

However, people feel more comfortable in the common area of Thecentre:mk and in the shops of Lakeside Shopping Centre.

Coherently to this, in relation to the comfort of the whole building, the shoppers seem to be more satisfied in Thecentre:mk and the tenants in Lakeside Shopping Centre.

8.4.4. Comparison of the results of the surveys with the environmental data

Comparing the results of the surveys with the environmental data collected by monitoring, it is possible to highlight how much efficiently the shopping centres are providing comfortable environments to the occupants.

In particular, three main issues will be compared: temperature, air quality and lighting.

The comparison will be referred to the common area only because the data recorded in the shops about temperature and lighting level are too different from one shop to another to make any kind of generalization, as already pointed out in Chapter 7.

In general, the *temperature* is considered satisfactory by interviewees in both shopping centres.

According to CIBSE Guide A[96], the recommended summer operative temperature range for shopping malls, assuming air-conditioned buildings, is 21-25 °C and this range corresponds to a predicted mean vote (PMV) of ± 0.5. As seen in Chapter 7, the average temperature recorded in the common area of both shopping centres is included in that range. So, the responses of shoppers are coherent with the collected data.

Previously, it was pointed out that people tend to feel slightly warm in the common area of Thecentre:mk and slightly cool in those of Lakeside Shopping Centre.

Figure 8.3 shows that in Thecentre:mk the temperature in the common area is perceived as warmer in the afternoon than in the morning, while in Lakeside Shopping Centre cooler in the morning than in the afternoon.

In effect, in Thecentre:mk the temperature difference between morning and afternoon is negligible: the temperature maintains between about 23 °C and 25 °C in the morning and rises just above 25 °C in the afternoon. In Lakeside Shopping Centre the temperature difference between morning and afternoon is pronounced: in the morning the temperature maintains between about 22 °C and 25 °C and in the afternoon increases considerably over 25 °C.

Figure 8.4 shows that the ambient temperature is cooler in the morning and warmer in the afternoon in the shops of both shopping centres.

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[96] *Environmental design*. CIBSE Guide A. 7th edition. Chartered Institution of Building Services Engineers (CIBSE). London, January 2006. Pages 1-7 – 1-10.

The increase of temperature in the shopping centres is due to the increasing occupant density and solar radiation through the glazing of the common area.

Improvements in the control of temperature especially in the shops are an important suggestion from people particularly in Lakeside Shopping Centre, as here the temperature is higher than in Thecentre:mk.

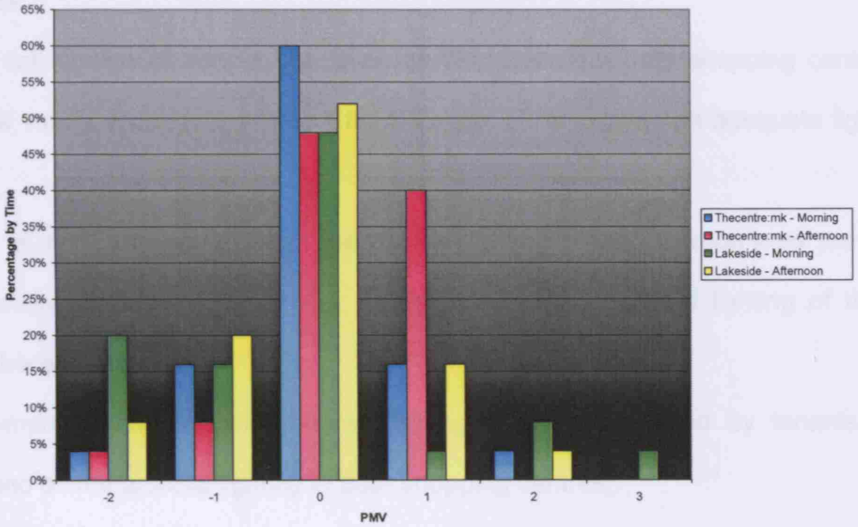

Figure 8.3. Comparison of the PMV in the area surveyed at the time of the survey by time of the day. (Scale: -3 = Cold, -2 = Cool, -1 = Slightly cool, 0 = Neutral, 1 = Slightly warm, 2 = Warm, 3 = Hot)

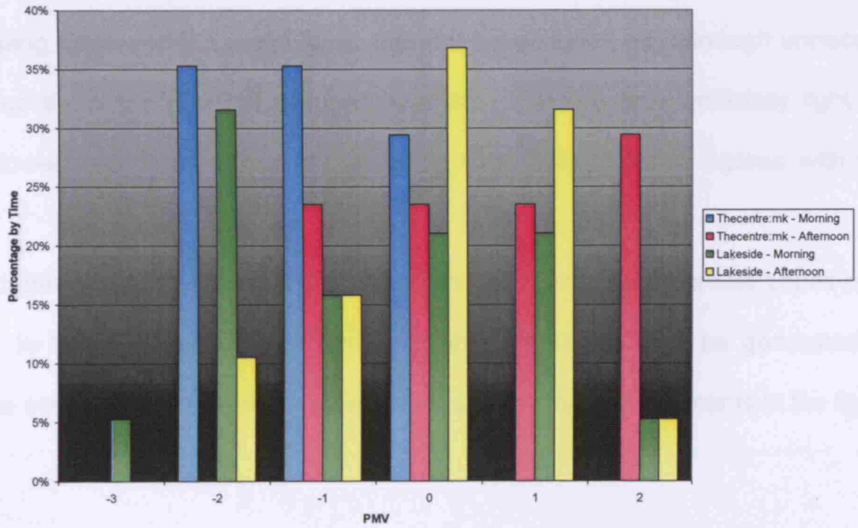

Figure 8.4. Comparison of the PMV in the shops surveyed at the time of the survey by time of the day. (Scale: -3 = Cold, -2 = Cool, -1 = Slightly cool, 0 = Neutral, 1 = Slightly warm, 2 = Warm, 3 = Hot)

The *air quality* is also considered satisfactory by interviewees in both shopping centres.

As seen in Chapter 7, the average and maximum CO_2 concentration in both shopping centres is lower than the values recommended by CIBSE Guides A[97]and B[98] for an adequate ventilation rate in a building.

Therefore, these CO_2 levels confirm the satisfaction of people for the air quality.

As the previous parameters, *lighting* in general is considered satisfactory by interviewees in both shopping centres.

In spite of the satisfaction of people, the average illuminance in both shopping centres is too low compared to the values recommended by CIBSE Guide A[99] to provide an adequate lighting, as seen in Chapter 7.

In confirmation of that, improvements on the natural lighting of the common area are suggested by shoppers especially in Lakeside Shopping Centre and on the artificial lighting of the same area particularly in Thecentre:mk.

In the shops improvements on the natural lighting are recommended by tenants especially in Thecentre:mk and on the artificial lighting in both shopping centres.

Actually, in both shopping centres the parts of the common area naturally lit up have an illuminance quite satisfactory that is not confirmed by the collected data, as pointed out in Chapter 7. In addition, as seen in Chapter 4, in Thecentre:mk there is not any presence of lights on in these areas, unlike Lakeside Shopping Centre where some lights can not be switched off, although unnecessary. In both shopping centres there are parts of the common area that are only artificially light up. Here, the illuminance is lower than in presence of natural lighting. This situation agrees with the suggested improvements.

Moreover, the different lighting levels in shops and common area easily create zones of high contrast in the visibility. In these cases glare or uncomfortable brightness may be generated. The latter is another possible source of discomfort and reason for suggesting improvements in the lighting.

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[97] *Environmental design.* CIBSE Guide A. 7th edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2006. Page 1-9 and 8-5.

[98] *Heating, ventilating, air conditioning and refrigeration.* CIBSE Guide B. Chartered Institution of Building Services Engineers (CIBSE). London. May 2005. Page 2-15.

[99] *Environmental design.* CIBSE Guide A. 7th edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2006. Page 1-9.

Chapter 9:

CONCLUSION AND FURTHER RECOMMENDATIONS

In the previous chapters, three factors have been considered as affecting energy efficiency of shopping centres: i) performance of the building fabric and services; ii) management of the building; iii) occupants' expectation for comfort and awareness of energy efficiency.

In relation to these elements, the aim of this dissertation has been to determine the role of the above factors in the energy consumption and carbon emissions of shopping centres and the scope for reducing this energy consumption by changing one or all the three factors. In addition, this dissertation has attempted to prioritize the changes in those factors that are more cost-effective at reducing that energy consumption.

This chapter intends to clarify the results of the previous analyses based on three case studies (Thecentre:mk, Lakeside Shopping Centre and Meadowhall Centre), focusing on the interaction of the above factors in the energy efficiency of shopping centres.

It has been found that the performance of the building fabric and services deeply affects the energy consumption and carbon emissions of shopping centres as well as the internal comfort. In this regard, the characteristics of building fabric and services are very important, but their patterns of use even more. Therefore, the management of shopping centres is greatly responsible for the performance of the existing building fabric and services.

As Chapters 4 and 5 showed, in the selected case studies appropriate decisions about the use of HVAC system, lighting system and equipment in terms of time and intensity, choices in the replacement of parts of these systems, maintenance and control of the same through the use of a BMS, have proved to be essential to reduce the energy consumption, providing a comfortable environment at the same time.

In some case studies a better control over the building services through the introduction of a BMS (e.g. in Thecentre:mk), and over the internal conditions through the appropriate use of sensors for temperature, humidity and illuminance (e.g. in Lakeside Shopping Centre) could be helpful for the management of the building.

As Chapters 7 and 8 illustrated, in two case studies (Thecentre:mk and Lakeside Shopping Centre) the internal environment have been found generally comfortable, as temperature, humidity and CO_2 concentration are in a range of values considered acceptable by CIBSE Guides and satisfactory in the opinion of the occupants.

In particular, satisfactory temperature and CO_2 concentration are achieved through a correct use of the HVAC system, provided of temperature and CO_2 sensors, and the application of an appropriate environmental policy (e.g. non-smoking policy). Instead, internal humidity has shown a strong dependence on the external one, which suggests a lack of a specific environmental control.

In Chapters 4 and 5, lighting has appeared to be a strong determinant of the electricity use, even more than cooling, making shopping centres and merchandise more attractive to visitors. However, it has turned out to be the most difficult environmental parameter to keep under control in all case studies, although improvements in this direction are already underway (e.g. in Thecentre:mk and Meadowhall Centre) or have been just introduced (e.g. in Lakeside Shopping Centre).

All the shopping centres analysed use natural lighting in the common area. This has appeared very appreciate by the occupants, as light through glazing has not a uniform distribution and gives people the perception of time and weather change. However, none of these shopping centres use solar shading systems to adjust the sunlight level. Solar radiations have been found affecting the internal temperature considerably in the case studies monitored, particularly Lakeside Shopping Centre. Overheating, especially in summer, requires additional ventilation and cooling, which in turn increases the energy consumption.

At the same time maximizing the use of natural lighting contributes to reduce the energy consumption due to artificial lighting. In fact, the use of photocell controls in Thecentre:mk and Meadowhall Centre has proved to produce an effective reduction in electricity usage and be useful to avoid possible glare in the occupants. Further reduction in electricity usage appears to have been achieved in Thecentre:mk and Meadowhall Centre through the introduction of efficient lamps and other dimming controls (e.g. occupants controls for the night).

Therefore, control over the environment has been found to be very important to reduce energy consumption and provide comfortable conditions inside the shopping centres. To achieve this control is responsibility of the management.

Nevertheless, there are two other factors that remarkably influence the energy consumption of shopping centres and over which the management has not direct control: the occupants and the weather conditions.

In particular, as seen in Chapter 5 for all the case studies, the number of occupants especially affects the electricity usage, as an increase in the occupancy involves an increase in ventilation and/or cooling demand during the whole year. The weather conditions also affect the electricity usage for lighting and cooling during all the seasons and both the electricity and gas usage for heating during winter period.

Occupants influence the overall performance of the building not only in terms of number but also by their expectation for comfort. According to this, the managers have to adjust the internal conditions with consequences on the energy consumption of shopping centres.

As Chapter 8 attested, people shopping and people working in shopping centres have a slightly different attitude toward comfort.

The shoppers really appreciate comfortable conditions inside the building. Nevertheless, the environmental conditions are not a priority in their decision of having a shopping trip. However, this does not mean that the internal conditions may not affect the visitors' choice of a shopping centre instead of another.

The shop assistants and shopkeepers are more critical towards the internal conditions compared to the customers, as they spend more time inside the building. Nonetheless, a few of them seem to be aware of the energy efficiency issue in shopping centres, as they are not involved in the management of the shops.

On the opposite, tenants should be more aware of the energy issue, as this basically turns out in lower services charges, costs of occupation and energy bills, as well as higher satisfaction of workers and visitors, as seen in Chapter 2.

Therefore, as resulted from Chapter 8, a big issue in the energy management of shopping centres is that people using the energy in the building (i.e. shoppers and shop assistants) are not the same ones that have control over the internal environment, energy consumption and bills (i.e. landlord over the common area and tenants over the shops).

In addition, people shopping and people working are not particularly concerned in saving energy, as this does not impact them directly. Landlord and tenants have separate management of common area and shops, and their related energy consumption and bills.

To prioritize the possible changes in one or more factors affecting the energy efficiency of shopping centres with the aim at reducing energy consumption, providing a comfortable environment at the same time, it is necessary to determine a breakdown of energy consumption by end-use and area. This allows introducing cost-effective energy saving measures in shopping centres.

An attempt to break down energy usage in the common area by end-use has been carried out by means of a regression analysis in Chapter 6. The results are not reliable because of the quality of data and lack of some essential information. In all case studies, the data of energy consumption related to the building are aggregate with those of other areas in the shopping centre (e.g. internal court in Thecentre:mk and car parks in Lakeside Shopping Centre and Meadowhall Centre).

In addition, common area and shops have different opening hours, building service systems and setting of temperature and other environmental parameters (humidity, illuminance, etc.). So, they reciprocally affect their environmental conditions and energy consumption.

Therefore, the implementation of sub-metering and agreement on setting target values for environmental parameters between landlord and tenants are extremely necessary to achieve an efficient use of energy in the building and improve the internal conditions.

As resulted from this dissertation, the quality of data and the knowledge of both environmental conditions and energy consumption of landlord's and tenants' areas are essential to clarify the performance of shopping centres and carry out future researches. As further development of this work, the breakdown of energy by end-use should be pursued to help the management of shopping centres to introduce cost-effective measures to reduce their energy consumption and carbon emissions, with benefits for the environment and all the actors involved in the operation and use of shopping centres.

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APPENDICES

Appendix A.1. Action checklist, published in GPG 134

1) Outside opening hours, switching off all lighting not essential for cleaners or security staff. It is possible to install time controls to switch off most lights automatically when the centre closes and to switch them on again the next morning.
   Potential savings: 10 % of lighting costs.

2) Checking the level of lighting in back-of-house areas such as service corridors. It is possible to switch off as many as half the lights while maintaining adequate lighting quality.
   Potential savings: 5 % of lighting costs.

3) Replacing tungsten lamps used for general lighting with more energy efficient compact fluorescent lamps (CFLs), so reducing both operating and maintenance costs. But a CFL has to be selected with the appropriate light distribution, output and colour.
   Potential savings: 75 % of lighting costs.

4) If the centre has daylight, installing photocell controls to switch off some of the lighting on bright days. It is possible to install detectors so that lights in less frequently used areas such as back-of-house corridors or staff toilets are on only when needed.
   Potential savings: 20 % of lighting costs.

5) Running escalators only during opening hours. It is possible to install time controls to switch them on and off automatically.
   Potential savings: 15 % of escalator power costs.

6) Switching off external and car park lighting when there is adequate daylight. Photocell controls combined with timers can control external lights cheaply and effectively.
   Potential savings: 60 % of outside lighting costs.

7) Using as little heating and air-conditioning as possible. It is possible to experiment with switch-on times; if the centre does not get busy until mid-morning, air-conditioning may not be needed until then. In winter it is possible to turn the heating off well before the centre closes.
   Potential savings: 20 % of heating and cooling costs.

8) Reducing the need for air-conditioning. The centre can be cooled by running the ventilation overnight, so reducing the need for air-conditioning during the day. If the centre has opening rooflights, it is possible to open them to provide natural ventilation on hot days.
   Potential savings: 20 % of cooling costs.

9) Setting cooling and heating thermostats correctly. It is possible to try increasing the temperature set-point for cooling and reducing the set-point for heating. Even a small change can reduce the shopping centre's bills dramatically.
   A 1 °C cut in temperature during the heating season can cut costs by around 10 %.

10) Never operating cooling and heating at the same time. It is possible to leave a wide "dead-band" between their settings or, better still, switch off the boilers in spring and the chillers in autumn.
    Potential savings: 10 % of heating costs[100].

Further information about opportunities for energy savings in shopping centres can be found in the following Carbon Trust's publications referred to the retail sector in general:

- *Energy efficiency action pack – for retail premises.* Good Practice Guide 190 (GPG 190). Energy Efficiency Best Practice Programme (EEBPP). Department of the Environment (DOE). Building Research Establishment Support Unit (BRECSU). Garston. June 1996.

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Appendix A.2. BREEAM Retail 2006

The BREEAM Retail 2006 scheme can be used to carry out environmental assessments of shopping malls, at four different stages in the building life cycle:

- new build or major refurbishment,
- post-construction,
- tenant fit-out,
- existing (occupied) operation and management.

It expresses the performance of the building as a BREEAM rating. Ratings range from "Pass", "Good", "Very Good" to "Excellent". The system is flexible and there are no mandatory performance levels other than statutory minimum requirements.

The topics assessed include energy, which covers the following issues:

- building fabric heat losses and avoiding air infiltration;
- internal and external lighting efficiency and strategy, and display lighting;
- energy and tenancy sub-metering;
- specification of space and water heating, mechanical ventilation and air-conditioning plant;
- maintenance schedules;

- building management system;
- renewable and low carbon energy use;
- passive solar design;
- services whole life performance;
- cold food storage and drink coolers;
- kitchen and bakery layout, and laundry and dry cleaning equipment;
- lifts, escalators and travelling walkways;
- energy management.

Assessments are carried out by independent assessor organisations that are licensed and trained by BRE. For each assessment, the assessor will produce a report outlining the development's performance against each of the criteria and its overall score and BREEAM rating. Upon satisfactory completion of the assessment, the client is presented with a certificate that confirms the development's BREEAM rating.

BREEAM Retail is reviewed annually to ensure that it remains representative of current best practice and takes account of technical and legislative changes[101].

Appendix A.3. Upstream's 2005 Environmental Benchmarking for Shopping Centres

The Upstream environmental benchmarking for shopping centres service helps owners and managers of shopping centres to compare and track quantified levels of performance in key environmental impact areas.

The headline indicators have been selected on the basis of their environmental significance, the degree of landlord managerial control and the availability of data.

[101] BREEAM Retail. http://www.breeam.org/retail.html, accessed August 2006.

Given the above criteria, there are four areas of environmental impact currently assessed, among which CO_2 emissions, associated with building energy consumption.

The essence of benchmarking is the comparison of performance and learning how to improve performance. Upstream's performance benchmarking makes comparisons against appropriate peers and over time.

Participants complete a user-friendly questionnaire and returns are screened for anomalies before analysis and interpretation.

To assess CO_2 emissions, the data required are kWh of energy (electricity, gas, others) from common services, excluding car park where possible, converted to CO_2 emissions, using U.K. government figures.

The data are normalized for weather and opening hours, and per m^2 area of common parts.

The properties are categorised by generic type (enclosed with A/C, enclosed without A/C and open) and near peers.

The performance of each property is compared against its performance over time (tracking trends), that of its "near peer" group (peers' trend) and that of other properties of its portfolio. In addition, there is a comparison portfolio by portfolio.

The rating is expressed by "smiley face" symbols, differentiated by colour and size, which provide a visual overview of change over time and relative performance.

At the end, each participant receives the following outputs:

- a confidential survey report with both strategic and practical recommendations, on a centre-by-centre basis, for improving environmental management;
- a presentation of the findings and recommendations to senior management within the company;
- an additional presentation to participating shopping centre managers;
- a complete record of the data submitted for the whole portfolio;
- automated spreadsheet tools that link centre-level targets with the portfolio-level picture[102].

[102] Upstream. http://www.upstreamstrategies.co.uk/, accessed August 2006.

Appendix B.1. Energy audits

An *energy audit* is an attempt to allocate a value to each item of end-use energy consumption over a given period and to balance these against overall energy use.

An energy audit is undertaken to identify where energy is being used. It is then possible to direct energy efficiency action towards the highest consumers. Energy audits can bring to light and eliminate hitherto unknown mistakes and/or unnecessary uses of energy. Auditing can use different analysis techniques, such as league tables, performance indicators, regression analysis, trend logging, CUSUM analysis and end-use benchmarking.

A simple preliminary audit deals primarily with energy bills, and therefore does not involve a detailed site investigation. An improved audit is often possible where site records of sub-meter readings are kept. A full audit requires breaking down energy end-use on a service-by-service basis. The process normally involves measurement, analysis or direct assessment of energy consumption to indicate the proportions attributable to heating, cooling, ventilation, air-conditioning, lighting or other major uses. Such information can only be obtained by performing a site survey[103].

Appendix B.2. Energy surveys

An *energy survey* is an on-site technical investigation of the supply, use and management of energy to identify specific energy saving measures.

The aim of a comprehensive survey is to reach a detailed breakdown of end-uses and the constituent parts of typical load patterns. This allows the principal consumers to be identified and, in particular, the base load. This is particularly helpful in indicating possible opportunities for reducing energy consumption.

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[103] *Energy efficiency in buildings.* CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Pages 18-2 – 18-3.

The survey covers the main items affecting energy use, including the following:

- *building*: levels of insulation, ventilation, air infiltration, etc.;
- *pattern of use*: periods of occupancy, the types of control, the temperatures and humidities maintained, the use of electric lighting, the activities and processes being undertaken, including their operating temperatures, insulation, etc.;
- *energy supply*: examination of energy supply and distribution arrangements;
- *main building services*: primary heating, cooling and air handling plant;
- *electric lighting*: quality, illuminance, luminance efficiency, extent to which daylight could reduce energy use, flexibility of control, etc.;
- *transport of energy within the building*: fans and pumps, insulation of hot water and steam pipes and air ducts, evidence of leakage, etc.;
- *plant room*: state and condition, insulation of boilers, chillers, tanks, pipe work, recovery of condensate, plant efficiency checks, etc.;
- *small power*: both on occupied floors and in common areas;
- *energy management*: determining who is responsible for energy management in each department, how energy consumption is reviewed, recorded and analysed, monitoring and target setting, investment, planning and maintenance;
- *building performance*: compared to standard benchmarks;
- *identification of opportunities*: for energy and cost savings with recommendations for action[104].

[104] *Energy efficiency in buildings*. CIBSE Guide F. 2nd edition. Chartered Institution of Building Services Engineers (CIBSE). London. January 2004. Page 18-3 – 18-4.

Appendix C.1. Mall facts and statistics – Thecentre:mk

Location:	Milton Keynes, U.K.
Opening date:	1979
Architect:	Milton Keynes Development Corporation
Developer:	Milton Keynes Development Corporation
Management:	Central Milton Keynes Shopping Management Company Ltd.
Owner:	Hermes Property Asset Management Ltd.
	Prudential Property Investment Managers Ltd.
No. of visitors:	over 29.5 million visitors a year[105]
Catchment population:	20 million people within 2 hours' drive time[106]
Total retail floor area:	79,124 m^2 (852,000 ft^2)[107]
No. of floors:	1
No. of stores and services:	174 (166 shop units, 8 anchor stores, 19 speciality barrows and kiosks and 19 cafés and restaurants)
Opening times:	Monday to Wednesday: 9:30 – 18:00
	Thursday and Friday: 9:30 – 20:00
	Saturday: 9:00 – 18:00
	Sunday and bank holidays: 11:00 – 17:00

[105] Source: Independent Retail and Property Consultancy Group, Experian 2001 revised report endorsed by BCSC. From: *Thecentre:mk Fact File*. July 2004. Page 5. Thecentre:mk. http://www.thecentremk.com/Documents/fact-file-July-04.pdf, accessed August 2006.
[106] *Thecentre:mk Fact File*. July 2004. Page 6. Thecentre:mk. http://www.thecentremk.com/Documents/fact-file-July-04.pdf, accessed August 2006.
[107] *Assessment of Specific Energy Savings Opportunities for The Centre MK.* Briar Associates. The Carbon Trust Programme. 16th April 2006. Page 1.

Appendix C.2. Mall facts and statistics – Lakeside Shopping Centre

Location:	West Thurrock, U.K.	
Opening date:	1990	
Architect:	Chapman Taylor Partners	
Structural engineer:	L.G. Mouchel & Partners	
Mechanical and engineering consultant:	Ronald Ward & Associates	
Landscape Architect:	A.C. Design	
Developer:	Broadway Construction & Development (Thurrock) Ltd. (a wholly owned subsidiary of Capital & Counties)	
Management:	Capital Shopping Centres (a wholly owned subsidiary of Liberty International)	
Owner:	Capital Shopping Centres	
No. of visitors:	24 million visitors a year[108], with an average of 450,000 visitors per week[109]	
Catchment population:	11 million people within 1 hours' drive time[110]	
Total retail floor area:	130,339 m^2 (1,403,000 ft^2)[111]	
No. of floors:	3	
No. of stores and services:	212 (200 shop units, 12 anchor stores, 33 cafés and restaurants)	
Opening times:	Monday to Friday:	10:00 – 22:00
	Saturday:	9:00 – 19:30
	Sunday:	11:00 – 17:00
	Bank holidays:	10:00 – 19:00

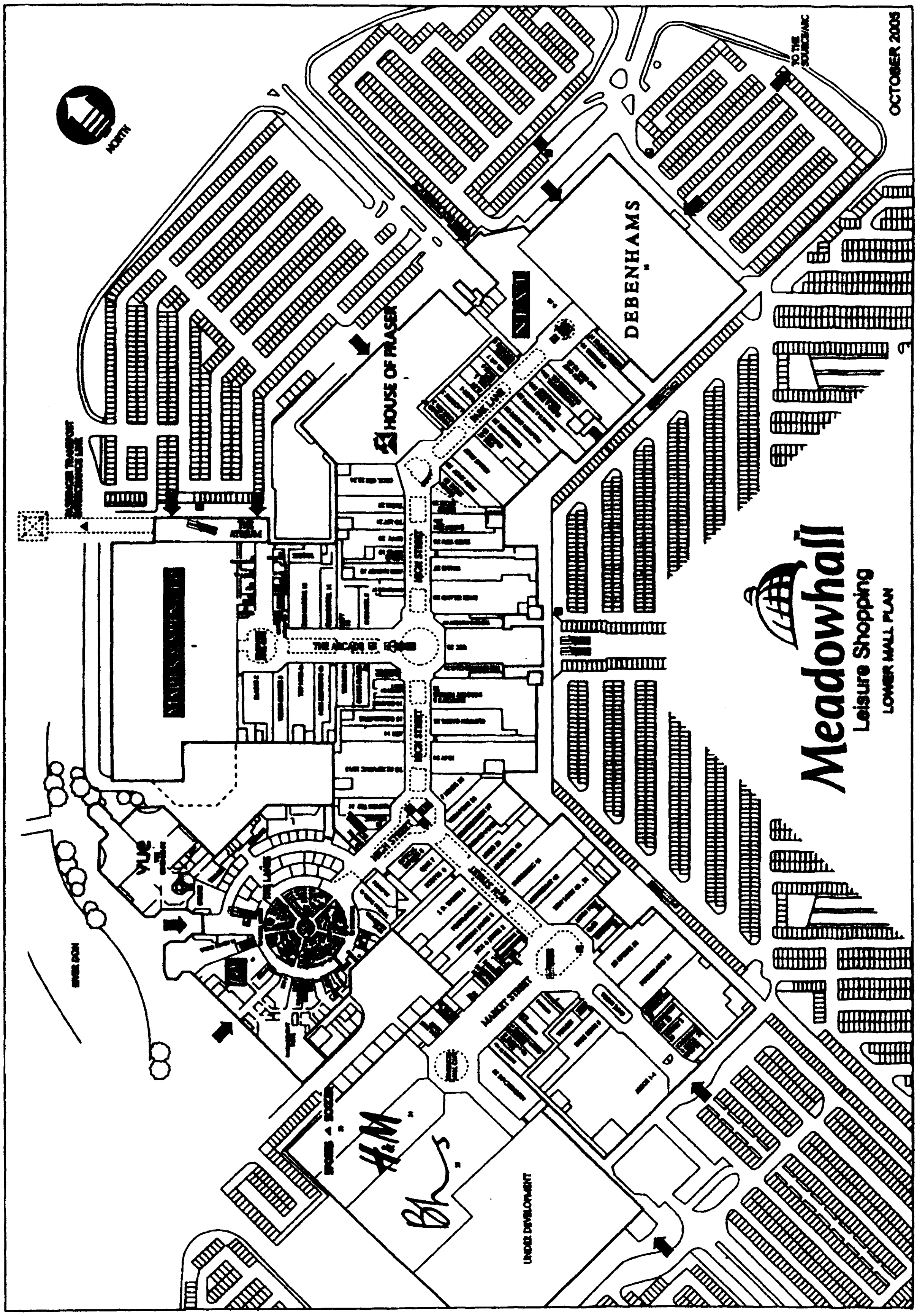
[108] Capital Shopping Centre Plc. (CSC). http://www.capital-shopping-centres.co.uk/shoppingcentres/lakeside/, accessed August 2006.
[109] Lakeside Shopping Centre. http://www.lakeside.uk.com/pages/careers/students.mhtml, accessed August 2006.
[110] *Lakeside Brochure*. Capital Shopping Centre Plc. (CSC). May 2006. http://www.capital-shopping-centres.co.uk/shoppingcentres/lakeside/pdf/brochure.pdf, accessed August 2006.
[111] Capital Shopping Centre Plc. (CSC). http://www.capital-shopping-centres.co.uk/shoppingcentres/lakeside/, accessed August 2006.

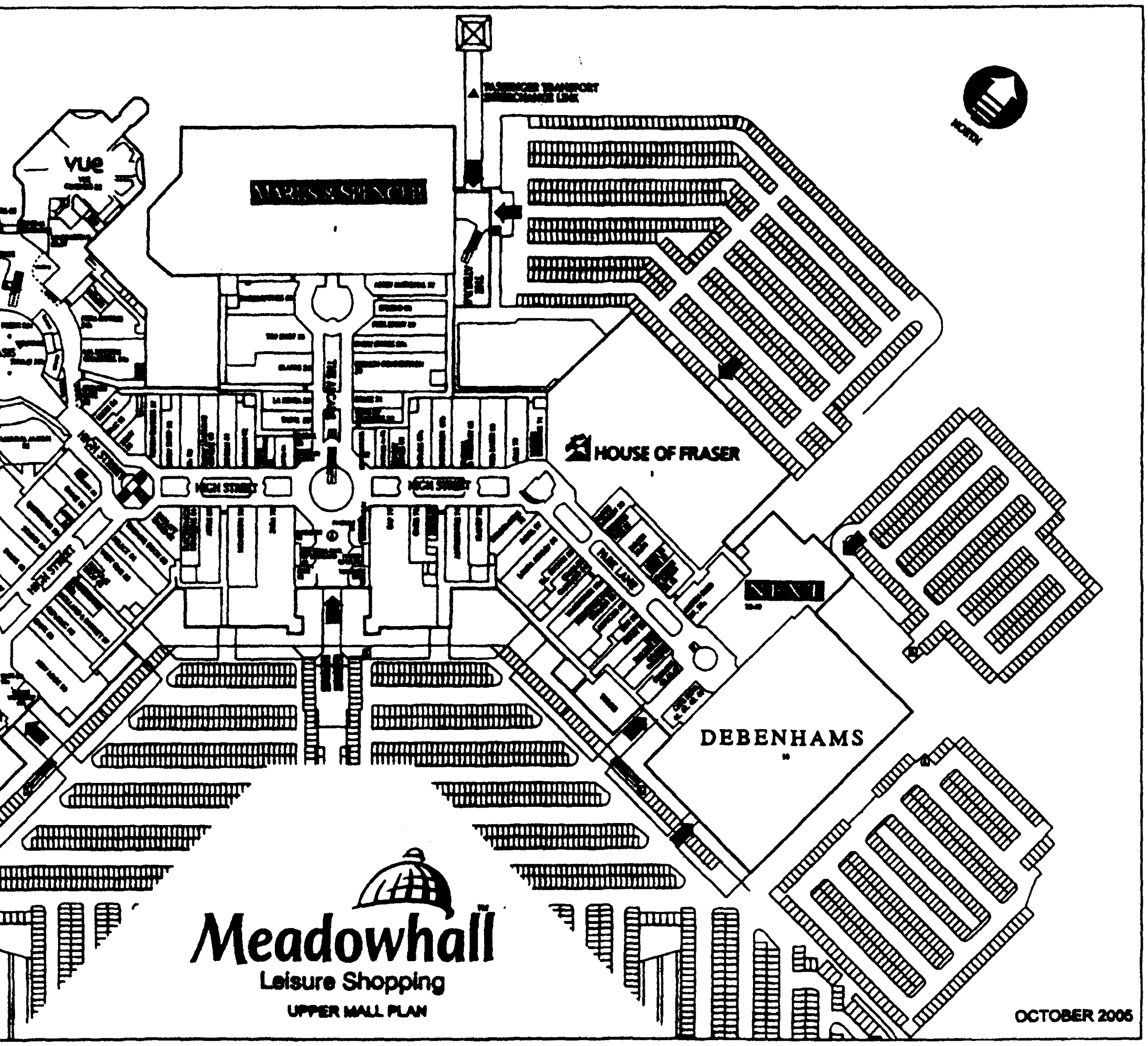
Appendix C.3. Mall facts and statistics – Meadowhall Centre

Location:	Sheffield, U.K.
Opening date:	1990
Architect:	Chapman Taylor Partners
Structural engineer:	Bingham Cotterell
Mechanical and engineering consultant:	Ferguson & Partners
Leisure consultant:	McCarthy & Associates Ltd.
Leisure design consultant:	RTKL Inc. (Dallas)
Developer:	Stadium Developments
Management:	Meadowhall Centre Ltd.
Owner:	British Land Company Plc.
No. of visitors:	over 25 million visitors a year[112], with an average of 800,000 visitors per week at peak time[113]
Catchment population:	9 million people within 1 hours' drive time[114]
Total retail floor area:	135,050 m^2 (1,453,000 ft^2)[115]
No. of floors:	2
No. of stores and services:	214 (205 shop units, 9 anchor stores, 26 speciality kiosks, 23 mall kiosks, 28 restaurants and cafés)
Opening times:	Monday to Friday: 10:00 – 21:00 Saturday: 9:00 – 19:00 Sunday: 11:00 – 17:00 Bank holidays: 10:00 – 18:00

[112] British Land. http://www.britishland.com/meadowhall.htm, accessed August 2006.
[113] British Land. http://www.britishland.com/meadowhall.htm, accessed August 2006.
[114] *Meadowhall Fact Pack*. Smith Young Property Consultant. April 2005. Page 1.
[115] *British Land Energy Benchmarking Phase 3. Energy Audits.* Ove Arup & Partners Ltd. British Land Carbon Management Programme. 20th April 2006. Pages 40-42.

Appendix C.4. Plans of Meadowhall Centre




Meadowhall
Leisure Shopping
UPPER MALL PLAN
OCTOBER 2005
DEBENHAMS
HOUSE OF FRASER
NEXT
MARKS & SPENCER
VUE
HIGH STREET
HIGH STREET
HIGH STREET
PARK LANE
PASSENGER TRANSPORT INTERCHANGE LINK
NORTH

Appendix C.5. Images of the case studies

View of the main mall (1), Middleton Hall (2) & Queens Court (3) in Thecentre:mk.

)

(2)

(3)

View of the main atrium (4), & mall (5) in Lakeside Shopping Centre.

(4)

(5)

(6)

(7)

(8)

View of the main dome area (6), main mall (7) & Oasis Food Court (8) in Meadowhall Centre.

Appendix D.1. Energy consumption data, carbon emissions results and external mean temperatures.

Thecentre:mk	Energy Consumption (kWh)			Energy Consumption per TFA (kWh/m^2)			Carbon Emissions (kg CO_2)			Carbon Emissions per TFA (kg CO_2/m^2)			External Mean Temperature (°C)
	Electricity	Gas	Total	Electricity	Gas	Total	Electricity	Gas	Total	Electricity	Gas	Total	
January	389,363	–	–	12	–	–	167,426	–	–	5.2	–	–	6.0
February	336,062	–	–	10	–	–	144,506	–	–	4.5	–	–	4.4
March	363,105	–	–	11	–	–	156,135	–	–	4.8	–	–	7.2
April	296,634	–	–	9	–	–	127,553	–	–	3.9	–	–	9.4
May	262,116	–	–	8	–	–	112,710	–	–	3.5	–	–	11.8
June	240,713	–	–	7	–	–	103,506	–	–	3.2	–	–	16.1
July	241,541	–	–	7	–	–	103,862	–	–	3.2	–	–	17.4
August	245,385	–	–	8	–	–	105,515	–	–	3.3	–	–	17.0
September	247,986	–	–	8	–	–	106,634	–	–	3.3	–	–	15.6
October	291,950	–	–	9	–	–	125,538	–	–	3.9	–	–	13.4
November	408,112	–	–	13	–	–	175,488	–	–	5.4	–	–	6.0
December	448,075	–	–	14	–	–	192,672	–	–	5.9	–	–	4.4
Year 2005	3,771,039	3,740,145	7,511,184	116	115	232	1,621,547	710,628	2,332,174	50.0	22.0	72.0	10.8
January	390,483	–	–	12	–	–	167,908	–	–	5.2	–	–	–
February	306,571	–	–	9	–	–	131,825	–	–	4.1	–	–	–
March	347,266	–	–	11	–	–	149,324	–	–	4.6	–	–	–
April	256,635	–	–	8	–	–	110,353	–	–	3.4	–	–	–
May	228,165	–	–	7	–	–	98,111	–	–	3.0	–	–	–
June	208,867	–	–	6	–	–	89,813	–	–	2.8	–	–	–
July	–	–	–	–	–	–	–	–	–	–	–	–	–
August	–	–	–	–	–	–	–	–	–	–	–	–	–
September	–	–	–	–	–	–	–	–	–	–	–	–	–
October	–	–	–	–	–	–	–	–	–	–	–	–	–
November	–	–	–	–	–	–	–	–	–	–	–	–	–
December	–	–	–	–	–	–	–	–	–	–	–	–	–
Year 2006	1,737,986	–	–	54	–	–	747,334	–	–	23.1	–	–	–

Appendix D.2. Energy consumption data, carbon emissions results and external mean temperatures.

Lakeside Shopping Centre	Energy Consumption (kWh)			Energy Consumption per TFA (kWh/m^2)			Carbon Emissions ($kg\ CO_2$)			Carbon Emissions per TFA ($kg\ CO_2/m^2$)			External Mean Temperature (°C)
	Electricity	Gas	Total	Electricity	Gas	Total	Electricity	Gas	Total	Electricity	Gas	Total	
January	–	–	–	–	–	–	–	–	–	–	–	–	6.7
February	–	–	–	–	–	–	–	–	–	–	–	–	4.9
March	–	–	–	–	–	–	–	–	–	–	–	–	8.0
April	–	–	–	–	–	–	–	–	–	–	–	–	10.4
May	–	–	–	–	–	–	–	–	–	–	–	–	13.1
June	–	–	–	–	–	–	–	–	–	–	–	–	17.9
July	–	–	–	–	–	–	–	–	–	–	–	–	18.7
August	–	–	–	–	–	–	–	–	–	–	–	–	18.1
September	–	–	–	–	–	–	–	–	–	–	–	–	17.1
October	–	–	–	–	–	–	–	–	–	–	–	–	14.5
November	–	–	–	–	–	–	–	–	–	–	–	–	7.1
December	–	–	–	–	–	–	–	–	–	–	–	–	5.1
Year 2005	–	–	–	–	–	–	–	–	–	–	–	–	11.8
January	1,402,185	1,105,333	2,507,518	28	22	51	602,940	210,013	812,953	12.2	4.3	16.5	–
February	1,209,117	1,295,703	2,504,820	25	26	51	519,920	246,184	766,104	10.6	5.0	15.6	–
March	1,358,505	1,216,586	2,575,091	28	25	52	584,157	231,151	815,308	11.9	4.7	16.6	–
April	1,144,883	545,254	1,690,137	23	11	34	492,300	103,598	595,898	10.0	2.1	12.1	–
May	1,138,128	81,709	1,219,837	23	2	25	489,395	15,525	504,920	9.9	0.3	10.3	–
June	1,196,533	34,261	1,230,794	24	1	25	514,509	6,510	521,019	10.4	0.1	10.6	–
July	–	–	–	–	–	–	–	–	–	–	–	–	–
August	–	–	–	–	–	–	–	–	–	–	–	–	–
September	–	–	–	–	–	–	–	–	–	–	–	–	–
October	–	–	–	–	–	–	–	–	–	–	–	–	–
November	–	–	–	–	–	–	–	–	–	–	–	–	–
December	–	–	–	–	–	–	–	–	–	–	–	–	–
Year 2006	7,449,351	4,278,846	11,728,197	151	87	238	3,203,221	812,981	4,016,202	65.1	16.5	81.6	–

Appendix D.3. Energy consumption data, carbon emissions results and external mean temperatures.

Meadowhall Centre	Energy Consumption (kWh)			Energy Consumption per TFA (kWh/m^2)			Carbon Emissions ($kg\ CO_2$)			Carbon Emissions per TFA ($kg\ CO_2/m^2$)			External Mean Temperature (°C)
	Electricity	Gas	Total	Electricity	Gas	Total	Electricity	Gas	Total	Electricity	Gas	Total	
January	1,094,801	133,771	1,228,572	33	4	37	470,764	25,416	496,181	14.2	0.8	15.0	5.7
February	973,248	83,033	1,056,281	29	3	32	418,497	15,776	434,273	12.6	0.5	13.1	3.9
March	1,060,788	88,698	1,149,486	32	3	35	456,139	16,853	472,991	13.8	0.5	14.3	7.2
April	901,465	63,757	965,222	27	2	29	387,630	12,114	399,744	11.7	0.4	12.1	8.8
May	865,741	27,349	893,090	26	1	27	372,269	5,196	377,465	11.2	0.2	11.4	11.1
June	810,134	26,533	836,667	24	1	25	348,358	5,041	353,399	10.5	0.2	10.7	15.0
July	817,276	38,056	855,332	25	1	26	351,429	7,231	358,659	10.6	0.2	10.8	16.2
August	830,966	12,539	843,505	25	0	25	357,315	2,382	359,698	10.8	0.1	10.9	15.8
September	818,965	15,249	834,214	25	0	25	352,155	2,897	355,052	10.6	0.1	10.7	14.4
October	890,914	20,367	911,281	27	1	27	383,093	3,870	386,963	11.6	0.1	11.7	12.7
November	1,061,757	87,300	1,149,057	32	3	35	456,556	16,587	473,143	13.8	0.5	14.3	5.3
December	1,133,207	67,306	1,200,513	34	2	36	487,279	12,788	500,067	14.7	0.4	15.1	4.2
Year 2005	11,259,262	663,958	11,923,220	340	20	360	4,841,483	126,152	4,967,635	146.1	4.0	150.1	10.1
January	1,010,665	95,907	1,106,572	30	3	33	434,586	18,222	452,808	13.1	0.5	13.6	–
February	901,755	108,005	1,009,760	27	3	30	387,755	20,521	408,276	11.7	0.6	12.3	–
March	953,840	136,918	1,090,758	29	4	33	410,151	26,014	436,166	12.4	0.8	13.2	–
April	847,056	51,847	898,903	26	2	27	364,234	9,851	374,085	11.0	0.3	11.3	–
May	867,278	-23,561	843,717	26	-1	25	372,930	-4,477	368,453	11.2	-0.1	11.1	–
June	880,509	88,038	968,547	27	3	29	378,619	16,727	395,346	11.4	0.5	11.9	–
July	–	–	–	–	–	–	–	–	–	–	–	–	–
August	–	–	–	–	–	–	–	–	–	–	–	–	–
September	–	–	–	–	–	–	–	–	–	–	–	–	–
October	–	–	–	–	–	–	–	–	–	–	–	–	–
November	–	–	–	–	–	–	–	–	–	–	–	–	–
December	–	–	–	–	–	–	–	–	–	–	–	–	–
Year 2006	5,461,103	457,154	5,918,257	165	14	179	2,348,274	86,859	2,435,134	70.8	2.6	73.4	–

Appendix D.4. Charts of the annual profiles of carbon emissions per TFA (2005 and 2006)

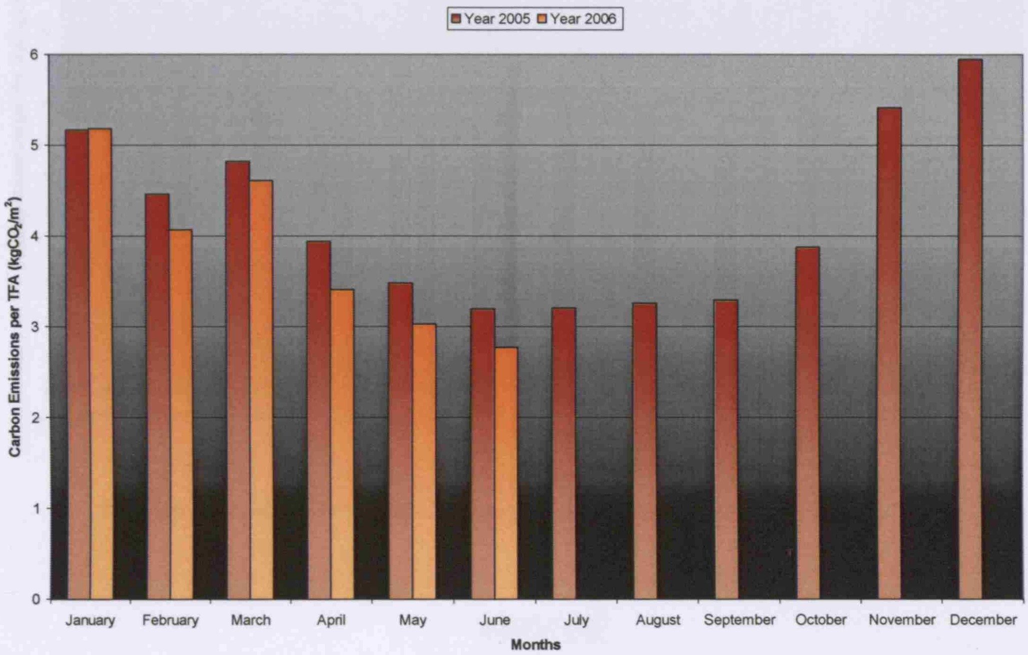


Figure D.4.1. Annual profiles of carbon emissions from electricity per TFA in Thecentre:mk (2005 and 2006).

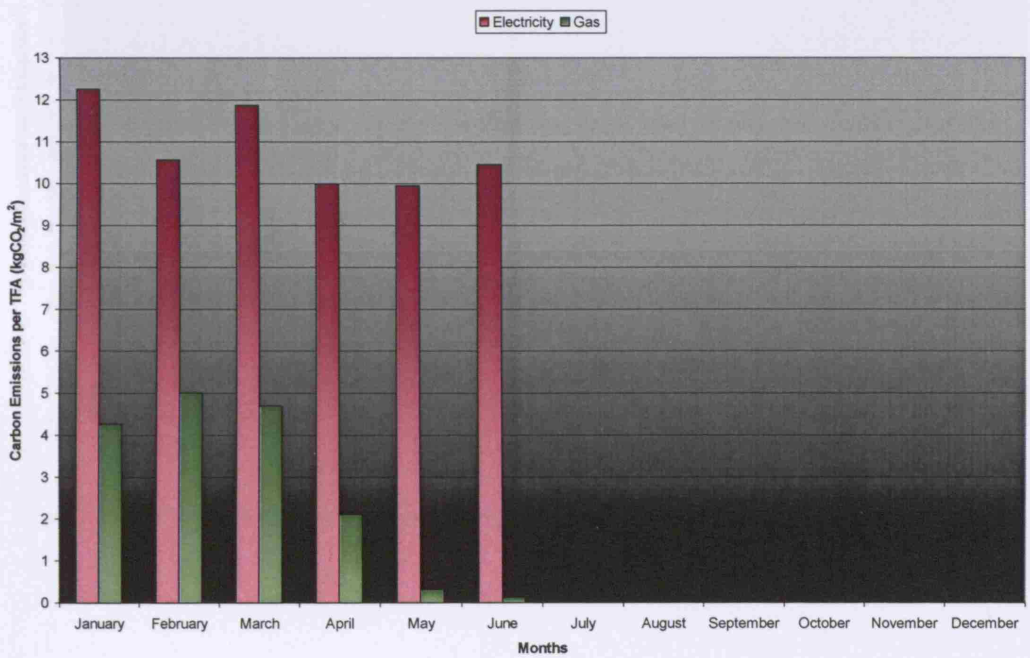


Figure D.4.2. Annual profile of carbon emissions per TFA in Lakeside Shopping Centre (2006).

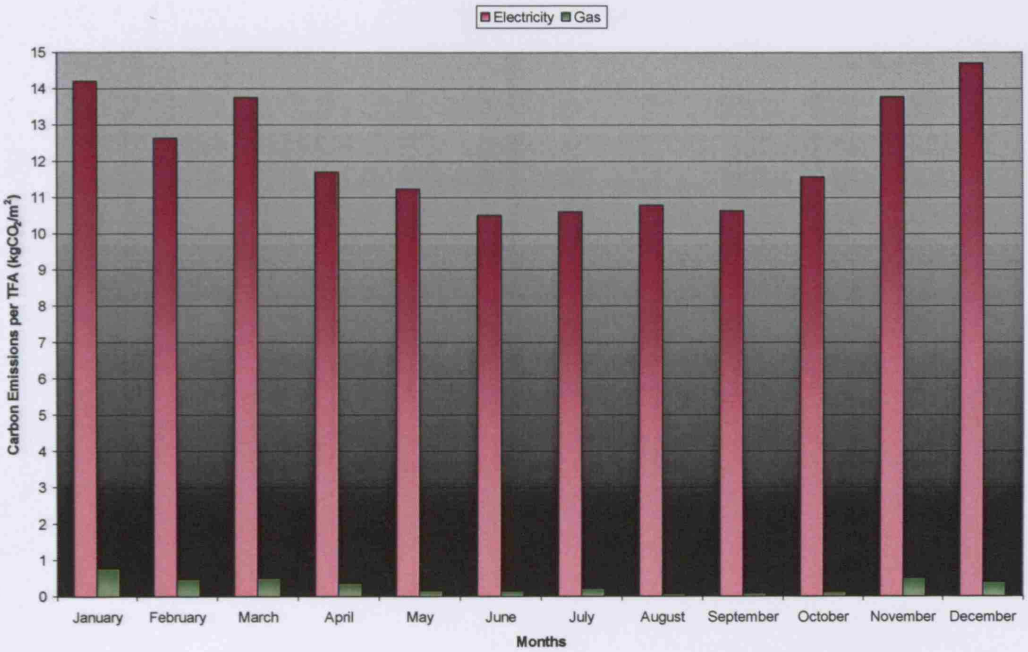


Figure D.4.3. Annual profile of carbon emissions per TFA in Meadowhall Centre (2005).

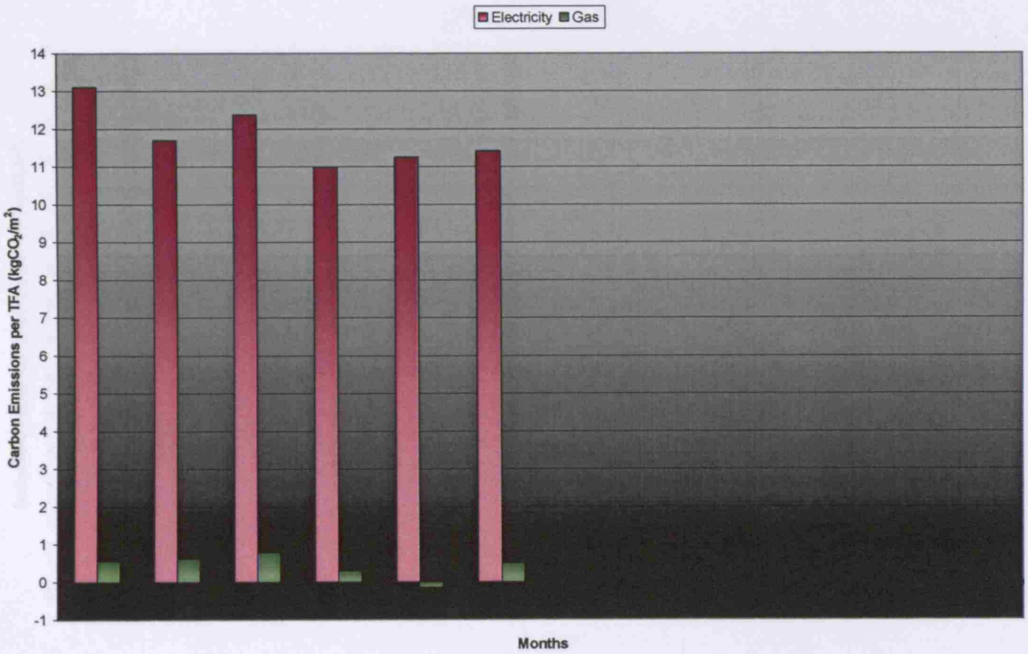


Figure D.4.4. Annual profile of carbon emissions per TFA in Meadowhall Centre (2006).

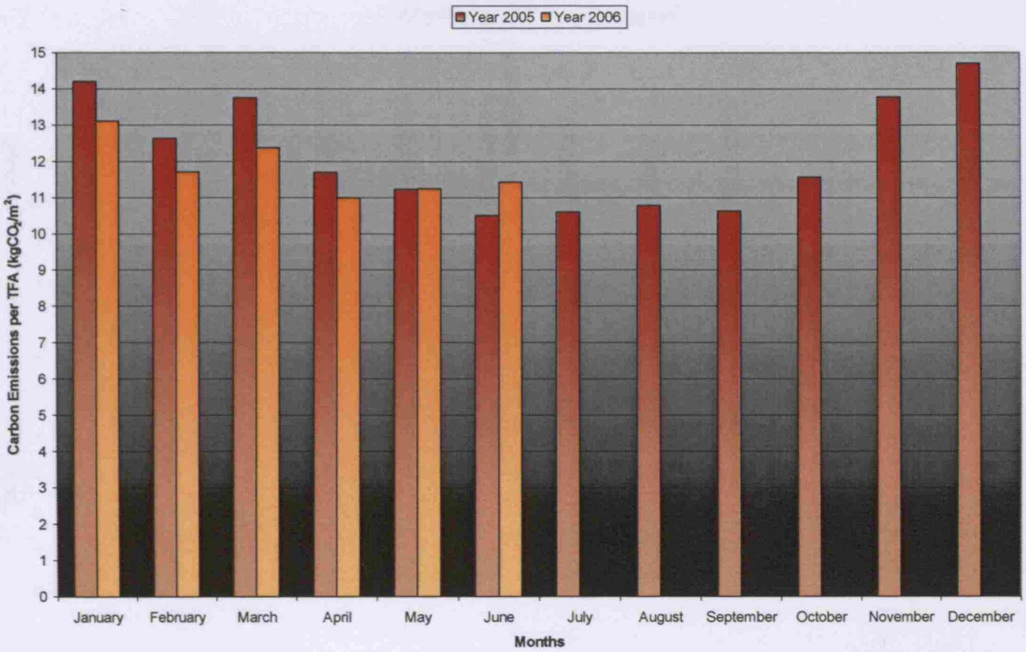


Figure D.4.5. Annual profiles of carbon emissions from electricity per TFA in Meadowhall Centre (2005 ad 2006).

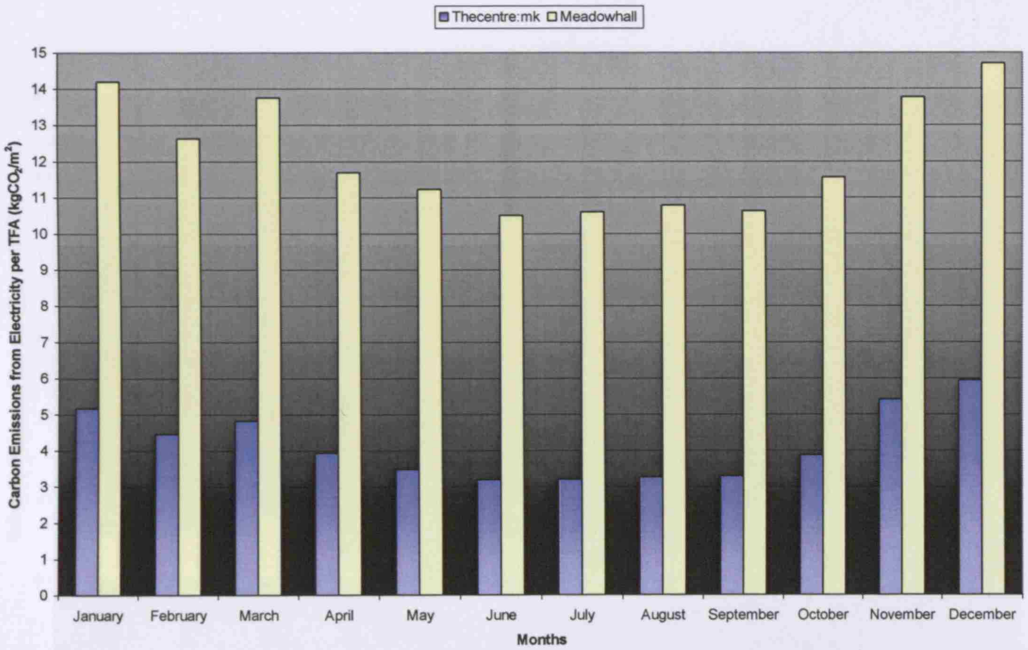


Figure D.4.6. Comparison of annual profiles of carbon emissions from electricity per TFA in Thecentre:mk and Meadowhall Centre (2005).

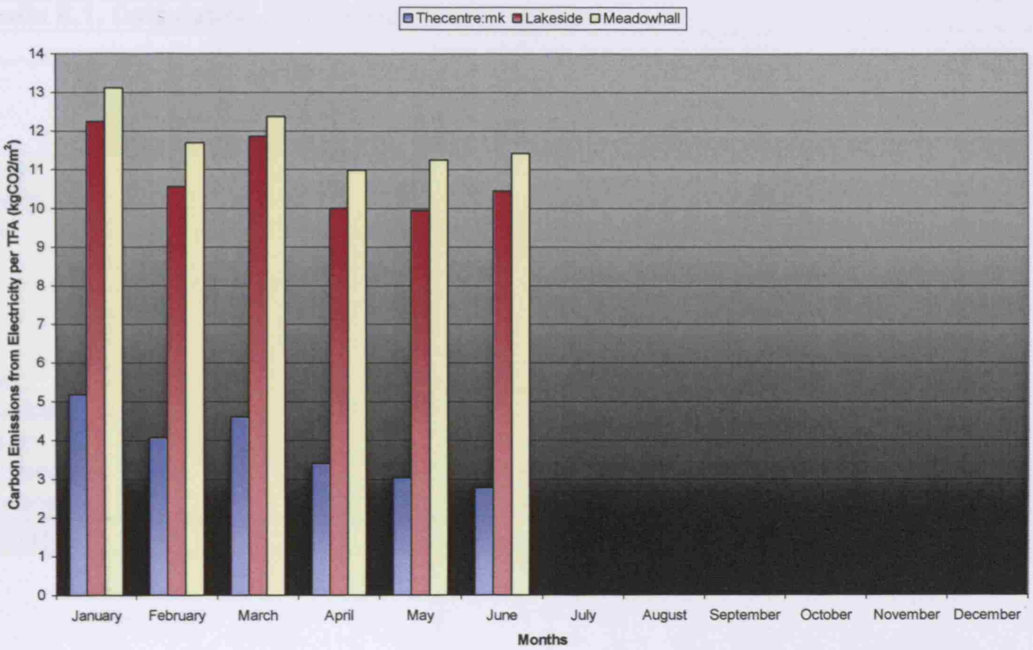


Figure D.4.7. Comparison of annual profiles of carbon emissions from electricity per TFA in Thecentre:mk, Lakeside Shopping Centre and Meadowhall Centre (2006).

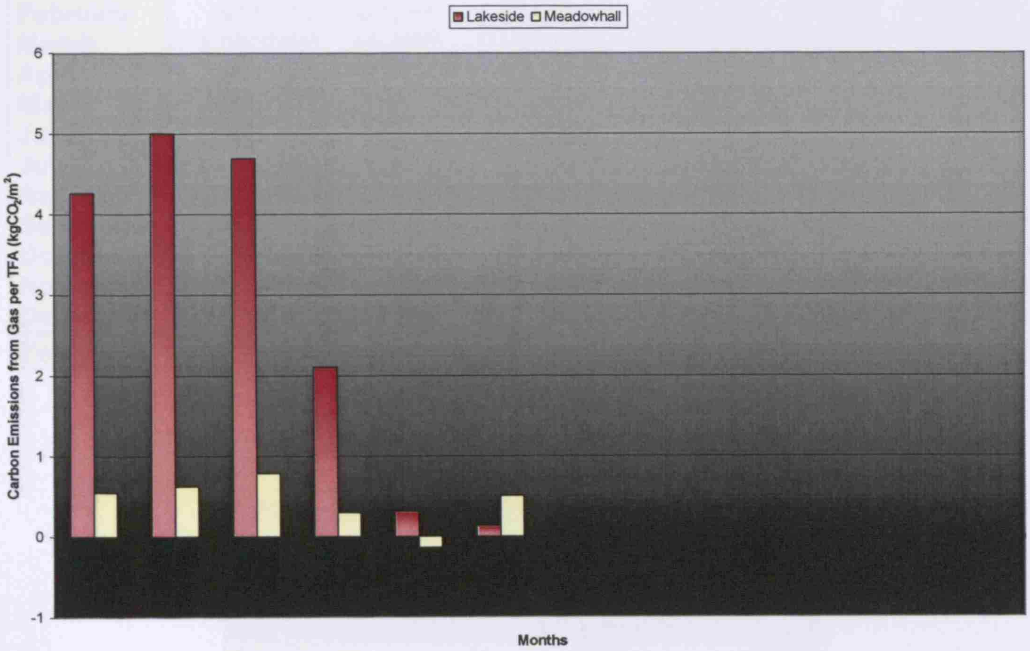


Figure D.4.8. Comparison of annual profiles of carbon emissions from gas per TFA in Lakeside Shopping Centre and Meadowhall Centre (2006).

Appendix E.1. Calculation of the temperature difference

	Internal Mean Temperature t_i (°C)	External Mean Temperature t_e (°C)	Temperature Difference $\Delta T = \Delta t = t_i - t_e$ (°C = K)
January	23.0	5.7	17.3
February	23.0	3.9	19.1
March	23.0	7.2	15.8
April	23.0	8.8	14.2
May	23.0	11.1	11.9
June	23.0	15.0	8.0
July	23.0	16.2	6.8
August	23.0	15.8	7.2
September	23.0	14.4	8.6
October	23.0	12.7	10.3
November	23.0	5.3	17.7
December	23.0	4.2	18.8
Year 2005	23.0	10.1	12.9

Appendix E.2. Data of the delivered energy and calculation of the useful energy

	Delivered Energy (kWh)			Useful Energy (kWh)		
	Electricity	Gas	Total	Electricity	Gas	Total
January	1,094,801	133,771	1,228,572	1,094,801	116,381	1,211,182
February	973,248	83,033	1,056,281	973,248	72,239	1,045,487
March	1,060,788	88,698	1,149,486	1,060,788	77,167	1,137,955
April	901,465	63,757	965,222	901,465	55,469	956,934
May	865,741	27,349	893,090	865,741	23,794	889,535
June	810,134	26,533	836,667	810,134	23,084	833,218
July	817,276	38,056	855,332	817,276	33,109	850,385
August	830,966	12,539	843,505	830,966	10,909	841,875
September	818,965	15,249	834,214	818,965	13,267	832,232
October	890,914	20,367	911,281	890,914	17,719	908,633
November	1,061,757	87,300	1,149,057	1,061,757	75,951	1,137,708
December	1,133,207	67,306	1,200,513	1,133,207	58,556	1,191,763
Year 2005	11,259,262	663,958	11,923,220	11,259,262	577,643	11,836,905

Appendix E.3. Calculation of the rate of F.H.L.

Building Element	U-value U (W/m^2K)	Area A (m^2)	Rate of F.H.L. $c_f = U \times A$ (W/K)
Rooflight	2.00	8,350	16,700
Roof	0.45	8,350	3,758
Floor	0.45	16,700	7,515
Total		33,400	27,973

Appendix E.4. Calculation of the number of opening hours per month.

Scenario A	No. of Days				No. of Hours per Day			No. of Hours per Month			
	Monday - Friday	Saturday	Sundays	Total	Monday - Friday	Saturday	Sundays	Monday - Friday	Saturday	Sundays	Total
January	21	5	5	31	12	10	6	252	50	30	332
February	20	4	4	28	11	10	6	220	40	24	284
March	23	4	4	31	11	10	6	253	40	24	317
April	21	5	4	30	11	10	6	231	50	24	305
May	22	4	5	31	11	10	6	242	40	30	312
June	22	4	4	30	11	10	6	242	40	24	306
July	21	5	5	31	11	10	6	231	50	30	311
August	23	4	4	31	11	10	6	253	40	24	317
September	22	4	4	30	11	10	6	242	40	24	306
October	21	5	5	31	11	10	6	231	50	30	311
November	22	4	4	30	12	10	6	264	40	24	328
December	22	5	4	31	12	10	6	264	50	24	338
Year 2005	260	53	52	365				2,925	530	312	3,767

Appendix E.5. Scenario A

In this scenario the energy consumption only corresponds to the opening time.

For the calculation of the number of hours a day the building is opened, peak and off-peak trading times have been considered, as shown in Table E.5.1.

Table E.5.1. Calculation of the number of opening hours a day.

	Off-Peak Trading Time February to October		Peak Trading Time November to January	
Days	**Opening times**	**No. of Hours**	**Opening times**	**No. of Hours**
Monday - Friday	10:00 to 21:00	11	10:00 to 22:00	12
Saturday	09:00 to 19:00	10	09:00 to 19:00	10
Sunday	11:00 to 17:00	6	11:00 to 17:00	6

By multiplying the number of hours a day by the number of days per month, distinguishing between weekdays and weekends, the number of opening hours per month has been determined, as shown in Table E.5.2. For the complete calculation of the number of opening hours per month see Table E.4.

Table E.5.2. Summary of the number of opening hours per month.

	No. of Hours per Month (h)
January	332
February	284
March	317
April	305
May	312
June	306
July	311
August	317
September	306
October	311
November	328
December	338
Year 2005	3,767

The useful energy per hour is determined by multiplying the useful energy by the number of opening hours per month, as shown in Table E.5.3. The values obtained are converted in watts.

Table E.5.3. Calculation of the useful energy per hour.

	Useful Energy per Hour (kW)			Useful Energy per Hour (W)		
	Electricity	Gas	Total	Electricity	Gas	Total
January	3,298	351	3,648	3,297,593	350,544	3,648,138
February	3,427	254	3,681	3,426,930	254,362	3,681,291
March	3,346	243	3,590	3,346,334	243,430	3,589,764
April	2,956	182	3,137	2,955,623	181,864	3,137,487
May	2,775	76	2,851	2,774,811	76,262	2,851,073
June	2,647	75	2,723	2,647,497	75,437	2,722,934
July	2,628	106	2,734	2,627,897	106,459	2,734,356
August	2,621	34	2,656	2,621,344	34,413	2,655,757
September	2,676	43	2,720	2,676,356	43,355	2,719,711
October	2,865	57	2,922	2,864,675	56,975	2,921,650
November	3,237	232	3,469	3,237,064	231,558	3,468,622
December	3,353	173	3,526	3,352,683	173,243	3,525,927
Year 2005	35,829	1,828	37,657	35,828,808	1,827,902	37,656,710

Plotting the useful energy per hour versus the temperature difference, the scatterplot shown in Figure E.5.1 is obtained.

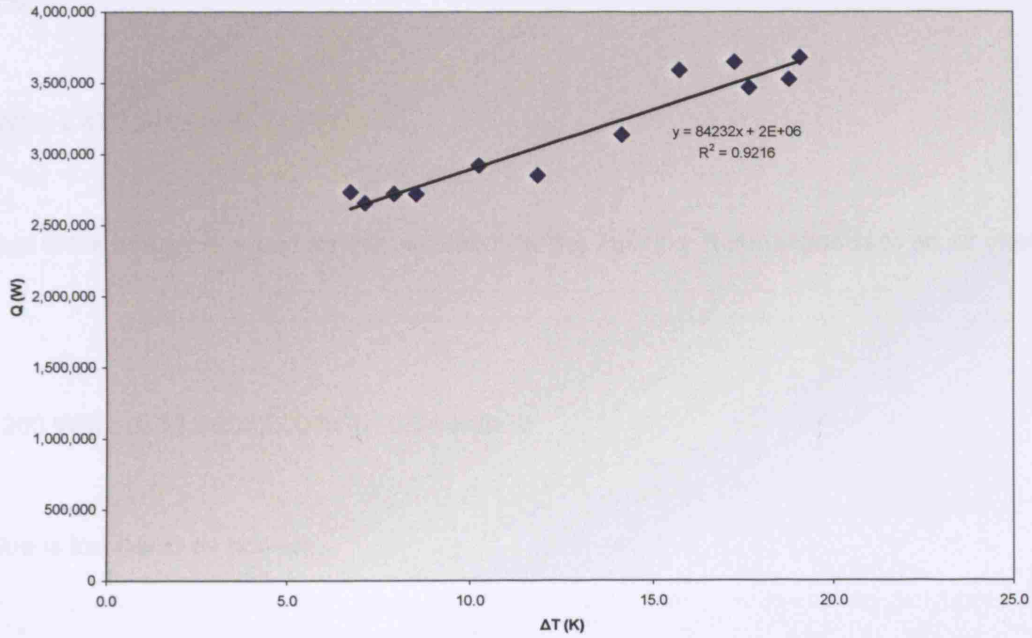


Figure E.5.1. Scatter plot of useful energy per hour versus temperature difference.

Performing a linear regression analysis, the fitted regression line has the following equation:

$Q = 84{,}232\ \Delta T + (2 \times 10^6)$

where the slope is:

$c_f + c_v = 84,232$ W/K

As the rate of F.H.L. is known, the rate of V.H.L., obtained by difference, is:

$c_v = 84,232$ W/K – 27,973 W/K = 56,260 W/K

By substituting the rate of V.H.L., the volumetric air flow rate is calculated as follows:

$q_v = 56,260$ W/K / (0.33 W/m^{3}K x 3,600 s) = 47.356 m^3/s = 47,356 l/s

Knowing the volumetric air flow rate and assuming a SFP of 2 W/l/s, the total electrical power required for fans is:

$P_e = 2$ W/l/s x 47,356 l/s = 94,713 W

This value is the energy required for the ventilation of the building. It corresponds to an air change rate of:

N = 56,260 W/K / (0.33 x 267,200 m^3) = 0.64 ac/h

This value is too low to be correct.

Appendix E.6. Scenario B

In this scenario the energy consumption corresponds to 24 hours of operation of the building services. The number of operation hours of the building services per month is determined by multiplying 24 hours by the number of days per month, as shown in Table E.6.1.

Table E.6.1. Calculation of the number of operation hours of the building services per month.

	No. of Days per Month	No. of Hours per Day	No. of Hours per Month
January	31	24	744
February	28	24	672
March	31	24	744
April	30	24	720
May	31	24	744
June	30	24	720
July	31	24	744
August	31	24	744
September	30	24	720
October	31	24	744
November	30	24	720
December	31	24	744
Year 2005	365	24	8760

The useful energy per hour is determined by multiplying the useful energy by the number of operation hours of the building services per month, as shown in Table E.6.2. The values obtained are converted in watts.

Table E.6.2. Calculation of the useful energy per hour.

	Useful Energy per Hour (kW)			Useful Energy per Hour (W)		
	Electricity	Gas	Total	Electricity	Gas	Total
January	1,472	156	1,628	1,471,507	156,426	1,627,932
February	1,448	107	1,556	1,448,286	107,498	1,555,784
March	1,426	104	1,530	1,425,790	103,719	1,529,510
April	1,252	77	1,329	1,252,035	77,040	1,329,074
May	1,164	32	1,196	1,163,630	31,981	1,195,611
June	1,125	32	1,157	1,125,186	32,061	1,157,247
July	1,098	45	1,143	1,098,489	44,501	1,142,990
August	1,117	15	1,132	1,116,890	14,663	1,131,552
September	1,137	18	1,156	1,137,451	18,426	1,155,877
October	1,197	24	1,221	1,197,465	23,816	1,221,281
November	1,475	105	1,580	1,474,663	105,488	1,580,150
December	1,523	79	1,602	1,523,128	78,705	1,601,832
Year 2005	15,435	794	16,229	15,434,520	794,322	16,228,842

Plotting the useful energy per hour versus the temperature difference, the scatterplot shown in Figure E.6.1 is obtained.

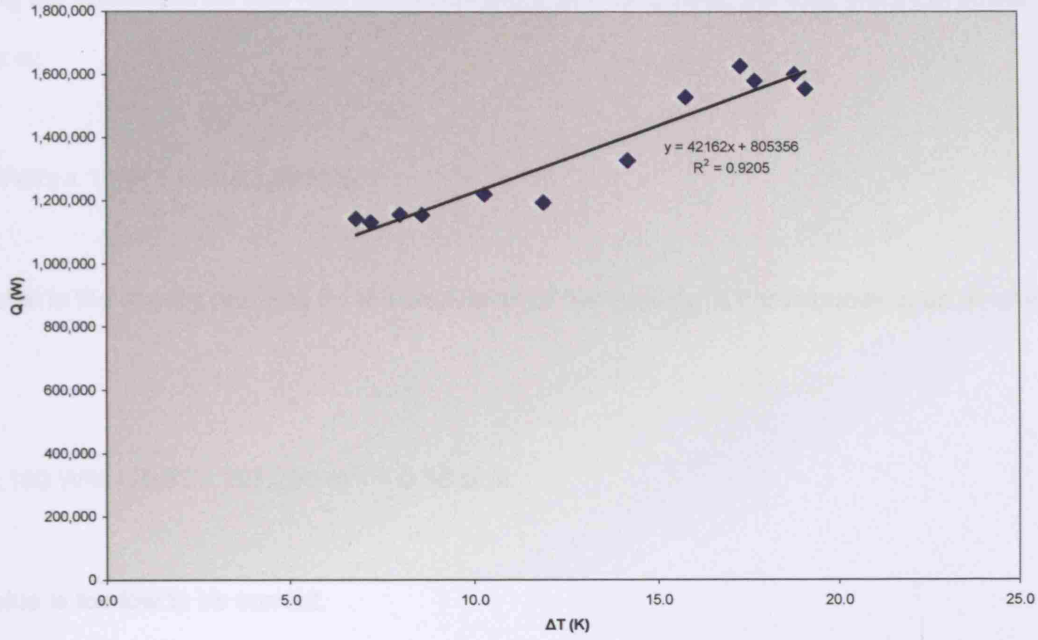


Figure E.6.1. Scatter plot of useful energy per hour versus temperature difference.

Performing a linear regression analysis, the fitted regression line has the following equation:

$Q = 42{,}162\ \Delta T + 805{,}356$

where the slope is:

$c_f + c_v = 42{,}162$ W/K

As the rate of F.H.L. is known, the rate of V.H.L., obtained by difference, is:

$c_v = 42{,}162$ W/K – 27,973 W/K = 14,190 W/K

By substituting the rate of V.H.L., the volumetric air flow rate is calculated as follows:

$q_v = 14{,}190$ W/K / (0.33 W/m^{3}K x 3,600 s) = 11.944 m^3/s = 11,944 l/s

Knowing the volumetric air flow rate and assuming a SFP of 2 W/l/s, the total electrical power required for fans is:

P_e = 2 W/l/s x 11,944 l/s = 23,888 W

This value is the energy required for the ventilation of the building. It corresponds to an air change rate of:

N = 14,190 W/K / (0.33 x 267,200 m^3) = 0.16 ac/h

This value is too low to be correct.

Appendix E.7. Calculation of base load gas consumption

Plotting the gas consumption (delivered energy) versus the temperature difference, the scatterplot shown in Figure E.7.1 is obtained.

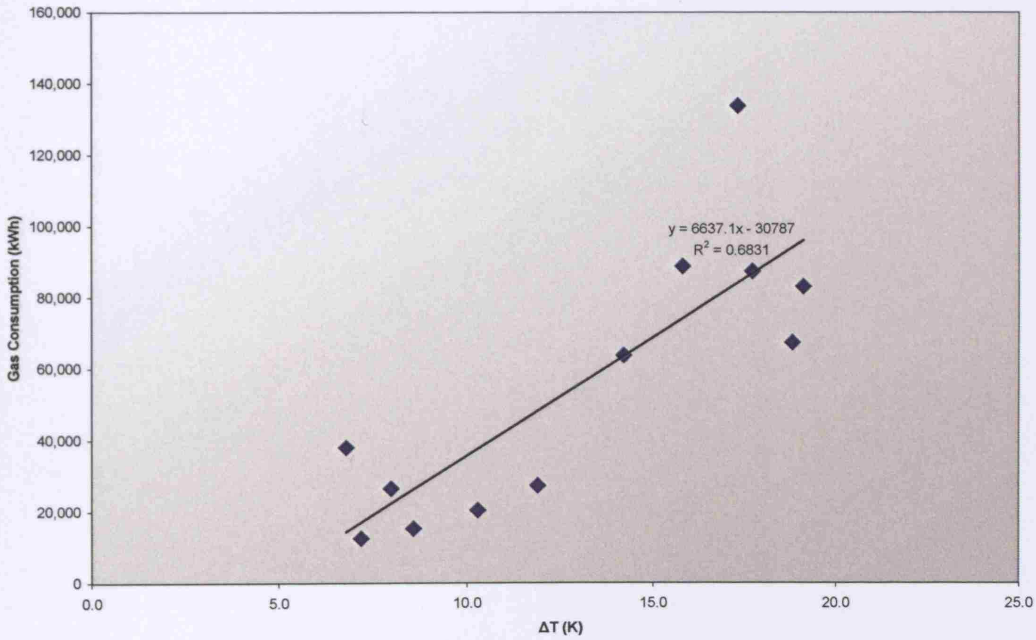


Figure E.7.1. Scatter plot of gas consumption versus temperature difference.

Performing a linear regression analysis, the fitted regression line has the following equation:

$$\text{Gas consumption} = 6{,}637.1\ \Delta T - 30{,}787$$

where the intercept (– 30,787 kWh) is negative. This value should represent the base load gas consumption for hot water, if it were positive.

Appendix F.1. Environmental data collected in Thecentre:mk from 11:00 on 8th July to 11:00 on 9th July, 2006.

Hour	Date/Time	Internal Temperature (°C)	External Temperature (°C)	Internal RH (%)	External RH (%)	Internal Absolute Humidity (g/m^3)	Internal Absolute Humidity (g/kg)	External Absolute Humidity (g/m^3)	External Absolute Humidity (g/kg)	Internal Intensity (lum/f^2)	Internal Intensity (lum/m^2)	Internal Voltage (V)	Internal CO_2 Concentration (ppm)
11:00	07/08/06 11:00	23.24	25.95	39.5	31.3	8.2	6.8	7.6	6.3	254	24	0.581	581
	07/08/06 11:12	23.63	33.59	38.2	24.0	8.1	6.8	8.8	7.3	375	35	0.591	591
	07/08/06 11:24	23.63	34.01	37.9	23.7	8.1	6.8	8.9	7.4	308	29	0.610	610
	07/08/06 11:36	23.63	31.12	36.7	23.7	7.8	6.5	7.6	6.3	222	21	0.610	610
	07/08/06 11:48	24.01	29.90	36.7	25.4	8.0	6.7	7.7	6.4	306	28	0.620	620
12:00	07/08/06 12:00	24.01	29.90	36.1	25.9	7.9	6.6	7.8	6.5	321	30	0.649	649
	07/08/06 12:12	24.40	34.43	36.0	24.0	8.0	6.7	9.2	7.7	368	34	0.659	659
	07/08/06 12:24	24.40	29.50	35.0	24.8	7.8	6.5	7.3	6.1	315	29	0.610	610
	07/08/06 12:36	24.79	31.52	34.6	23.8	7.9	6.6	7.8	6.5	390	36	0.688	688
	07/08/06 12:48	24.79	25.95	34.7	28.2	7.9	6.6	6.9	5.8	252	23	0.669	669
13:00	07/08/06 13:00	24.79	28.31	34.9	29.6	7.9	6.6	8.2	6.8	461	43	0.688	688
	07/08/06 13:12	24.40	24.40	35.4	32.5	7.9	6.6	7.2	6.0	197	18	0.679	679
	07/08/06 13:24	24.79	31.12	35.2	28.0	8.0	6.7	9.0	7.5	433	40	0.630	630
	07/08/06 13:36	25.17	29.10	35.0	26.0	8.1	6.8	7.5	6.3	317	29	0.688	688
	07/08/06 13:48	24.79	25.56	34.9	30.1	7.9	6.6	7.2	6.0	291	27	0.728	728
14:00	07/08/06 14:00	24.79	25.17	35.5	32.1	8.1	6.8	7.5	6.3	278	26	0.718	718
	07/08/06 14:12	25.17	25.17	35.2	34.0	8.2	6.8	7.9	6.6	446	41	0.708	708
	07/08/06 14:24	25.17	26.34	35.5	30.8	8.2	6.8	7.6	6.3	390	36	0.698	698
	07/08/06 14:36	25.56	24.79	35.3	34.0	8.4	7.0	7.7	6.4	328	30	0.767	767
	07/08/06 14:48	25.17	24.79	35.6	33.8	8.3	6.9	7.7	6.4	285	26	0.737	737
15:00	07/08/06 15:00	25.56	25.17	35.1	33.7	8.3	6.9	7.8	6.5	385	36	0.688	688
	07/08/06 15:12	25.56	25.17	34.6	32.9	8.2	6.8	7.7	6.4	338	31	0.718	718
	07/08/06 15:24	25.17	24.79	34.8	34.0	8.1	6.8	7.7	6.4	261	24	0.669	669
	07/08/06 15:36	25.56	24.79	34.2	33.2	8.1	6.8	7.6	6.3	315	29	0.728	728
	07/08/06 15:48	25.56	25.17	34.0	33.4	8.1	6.8	7.8	6.5	265	25	0.649	649
16:00	07/08/06 16:00	25.17	24.79	33.9	34.3	7.9	6.6	7.8	6.5	199	18	0.630	630
	07/08/06 16:12	25.56	24.79	34.5	35.5	8.2	6.8	8.1	6.8	289	27	0.679	679
	07/08/06 16:24	25.17	24.40	34.8	35.6	8.1	6.8	7.9	6.6	192	18	0.669	669
	07/08/06 16:36	25.17	24.01	35.2	38.0	8.2	6.8	8.3	6.9	285	26	0.669	669
	07/08/06 16:48	25.17	23.63	35.5	38.6	8.2	6.8	8.2	6.8	261	24	0.649	649
17:00	07/08/06 17:00	24.79	22.86	36.0	39.5	8.2	6.8	8.0	6.7	136	13	0.610	610
	07/08/06 17:12	24.79	22.48	36.2	41.1	8.2	6.8	8.2	6.8	274	25	0.601	601
	07/08/06 17:24	24.79	21.71	36.6	42.9	8.3	6.9	8.2	6.8	207	19	0.620	620
	07/08/06 17:36	24.79	22.86	36.7	40.4	8.3	6.9	8.2	6.8	276	26	0.591	591
	07/08/06 17:48	24.79	22.48	36.2	39.2	8.2	6.8	7.8	6.5	246	23	0.542	542
18:00	07/08/06 18:00	24.79	21.71	35.5	40.9	8.1	6.8	7.8	6.5	201	19	0.571	571
Average		24.80	26.43	35.6	32.2	8.1	6.7	7.9	6.6	296	28	0.656	656
	07/08/06 18:12	24.40		35.9		8.0	6.7			207	19	0.522	522
	07/08/06 18:24	24.40		36.3		8.1	6.8			154	14	0.493	493
	07/08/06 18:36	24.01		37.1		8.1	6.8			154	14	0.444	444
	07/08/06 18:48	23.63		38.0		8.1	6.8			128	12	0.425	425

Hour	Date/Time	Internal Temperature (°C)	External Temperature (°C)	Internal RH (%)	External RH (%)	Internal Absolute Humidity (g/m^3)	Internal Absolute Humidity (g/kg)	External Absolute Humidity (g/m^3)	External Absolute Humidity (g/kg)	Internal Intensity (lum/f^2)	Internal Intensity (lum/m^2)	Internal Voltage (V)	Internal CO_2 Concentration (ppm)
19:00	07/08/06 19:00	23.24		39.0		8.1	6.8			76	7	0.415	415
	07/08/06 19:12	23.24		40.2		8.4	7.0			66	6	0.405	405
	07/08/06 19:24	23.24		39.8		8.3	6.9			78	7	0.396	396
	07/08/06 19:36	22.86		39.5		8.0	6.7			55	5	0.386	386
	07/08/06 19:48	22.86		40.3		8.2	6.8			33	3	0.386	386
20:00	07/08/06 20:00	22.86		40.6		8.3	6.9			35	3	0.396	396
	07/08/06 20:12	22.48		40.7		8.1	6.8			20	2	0.396	396
	07/08/06 20:24	22.48		40.9		8.2	6.8			16	1	0.386	386
	07/08/06 20:36	22.48		41.2		8.2	6.8			10	1	0.386	386
	07/08/06 20:48	22.48		41.7		8.3	6.9			8	1	0.386	386
21:00	07/08/06 21:00	22.09		42.8		8.3	6.9			8	1	0.386	386
	07/08/06 21:12	22.09		43.5		8.5	7.1			5	0	0.386	386
	07/08/06 21:24	22.09		45.0		8.8	7.3			5	0	0.386	386
	07/08/06 21:36	22.09		45.5		8.9	7.4			3	0	0.386	386
	07/08/06 21:48	21.71		46.2		8.8	7.3			5	0	0.386	386
22:00	07/08/06 22:00	21.71		46.8		8.9	7.4			5	0	0.376	376
	07/08/06 22:12	21.71		46.8		8.9	7.4			5	0	0.386	386
	07/08/06 22:24	21.71		47.4		9.0	7.5			5	0	0.386	386
	07/08/06 22:36	21.71		47.4		9.0	7.5			3	0	0.396	396
	07/08/06 22:48	21.33		47.5		8.9	7.4			3	0	0.386	386
23:00	07/08/06 23:00	21.33		47.2		8.8	7.3			5	0	0.396	396
	07/08/06 23:12	21.33		47.2		8.8	7.3			3	0	0.386	386
	07/08/06 23:24	21.33		47.2		8.8	7.3			3	0	0.386	386
	07/08/06 23:36	20.95		47.5		8.7	7.3			5	0	0.376	376
	07/08/06 23:48	20.95		47.3		8.6	7.2			3	0	0.386	386
00:00	07/09/06 00:00	20.95		47.2		8.6	7.2			5	0	0.386	386
	07/09/06 00:12	20.95		47.2		8.6	7.2			3	0	0.386	386
	07/09/06 00:24	20.95		47.5		8.7	7.3			5	0	0.386	386
	07/09/06 00:36	20.95		48.2		8.8	7.3			3	0	0.386	386
	07/09/06 00:48	20.57		48.9		8.7	7.3			3	0	0.386	386
01:00	07/09/06 01:00	20.57		49.4		8.8	7.3			3	0	0.386	386
	07/09/06 01:12	20.57		50.0		8.9	7.4			3	0	0.386	386
	07/09/06 01:24	20.57		50.0		8.9	7.4			3	0	0.386	386
	07/09/06 01:36	20.57		50.7		9.0	7.5			3	0	0.386	386
	07/09/06 01:48	20.57		51.2		9.1	7.6			3	0	0.386	386
02:00	07/09/06 02:00	20.57		51.5		9.2	7.7			3	0	0.396	396
	07/09/06 02:12	20.57		52.2		9.3	7.8			3	0	0.386	386
	07/09/06 02:24	20.57		52.6		9.4	7.8			3	0	0.386	386
	07/09/06 02:36	20.57		52.0		9.3	7.8			3	0	0.386	386
	07/16/06 02:48	20.19		51.6		9.0	7.5			3	0	0.386	386
03:00	07/09/06 03:00	20.19		51.6		9.0	7.5			3	0	0.386	386
	07/09/06 03:12	20.19		51.6		9.0	7.5			3	0	0.376	376
	07/09/06 03:24	20.19		52.3		9.1	7.6			3	0	0.376	376
	07/09/06 03:36	20.19		53.0		9.3	7.8			5	0	0.386	386
	07/09/06 03:48	20.19		53.2		9.3	7.8			3	0	0.376	376

Hour	Date/Time	Internal Temperature (°C)	External Temperature (°C)	Internal RH (%)	External RH (%)	Internal Absolute Humidity (g/m^3)	Internal Absolute Humidity (g/kg)	External Absolute Humidity (g/m^3)	External Absolute Humidity (g/kg)	Internal Intensity (lum/f^2)	Internal Intensity (lum/m^2)	Internal Voltage (V)	Internal CO_2 Concentration (ppm)
04:00	07/09/06 04:00	20.19		54.0		9.4	7.8			3	0	0.376	376
	07/09/06 04:12	20.19		54.4		9.5	7.9			3	0	0.366	366
	07/09/06 04:24	20.19		54.8		9.6	8.0			3	0	0.376	376
	07/09/06 04:36	20.19		55.4		9.7	8.1			5	0	0.376	376
	07/09/06 04:48	19.81		56.2		9.6	8.0			3	0	0.376	376
05:00	07/09/06 05:00	19.81		56.4		9.6	8.0			3	0	0.376	376
	07/09/06 05:12	19.81		56.6		9.7	8.1			3	0	0.376	376
	07/09/06 05:24	19.81		57.0		9.7	8.1			5	0	0.386	386
	07/09/06 05:36	19.81		57.3		9.8	8.2			8	1	0.386	386
	07/09/06 05:48	20.19		57.2		10.0	8.3			14	1	0.376	376
06:00	07/09/06 06:00	19.81		57.5		9.8	8.2			27	3	0.376	376
	07/09/06 06:12	19.81		58.2		9.9	8.3			46	4	0.376	376
	07/09/06 06:24	20.19		58.4		10.2	8.5			46	4	0.376	376
	07/09/06 06:36	20.19		58.1		10.2	8.5			48	4	0.376	376
	07/09/06 06:48	20.19		58.1		10.2	8.5			93	9	0.376	376
07:00	07/09/06 07:00	20.19		58.1		10.2	8.5			46	4	0.376	376
	07/09/06 07:12	20.19		58.4		10.2	8.5			66	6	0.376	376
	07/09/06 07:24	20.19		58.1		10.2	8.5			156	14	0.376	376
	07/09/06 07:36	20.19		58.4		10.2	8.5			108	10	0.376	376
	07/09/06 07:48	20.57		58.3		10.4	8.7			207	19	0.376	376
08:00	07/09/06 08:00	20.57		58.0		10.4	8.7			78	7	0.376	376
	07/09/06 08:12	20.57		58.6		10.5	8.8			81	8	0.376	376
	07/09/06 08:24	20.57		59.1		10.5	8.8			108	10	0.386	386
	07/09/06 08:36	20.57		59.1		10.5	8.8			91	8	0.376	376
	07/09/06 08:48	20.57		58.6		10.5	8.8			143	13	0.376	376
09:00	07/09/06 09:00	20.57		59.1		10.5	8.8			100	9	0.386	386
	07/09/06 09:12	20.57		59.6		10.6	8.8			91	8	0.386	386
	07/09/06 09:24	20.57		60.2		10.7	8.9			100	9	0.386	386
	07/09/06 09:36	20.19		60.6		10.6	8.8			85	8	0.376	376
	07/09/06 09:48	20.57		61.4		11.0	9.2			111	10	0.386	386
10:00	07/09/06 10:00	20.57		60.8		10.9	9.1			128	12	0.386	386
	07/09/06 10:12	20.95		60.4		11.0	9.2			128	12	0.396	396
	07/09/06 10:24	20.95		60.4		11.0	9.2			130	12	0.425	425
	07/09/06 10:36	21.33		60.6		11.3	9.4			141	13	0.425	425
	07/09/06 10:48	21.71		60.5		11.5	9.6			154	14	0.454	454
11:00	07/09/06 11:00	21.71		59.9		11.4	9.5			379	35	0.464	464
Average		21.10		51.2		9.4	7.8			48	4	0.391	391
Average on 24 hrs		22.95		43.4		8.7	7.3			172	16	0.523	523

Appendix F.2. Environmental data collected in Lakeside Shopping Centre from 11:00 on 15th July to 11:00 on 16th July, 2006.

Hour	Date/Time	Internal Temperature (°C)	External Temperature (°C)	Internal RH (%)	External RH (%)	Internal Absolute Humidity (g/m^3)	Internal Absolute Humidity (g/kg)	External Absolute Humidity (g/m^3)	External Absolute Humidity (g/kg)	Internal Intensity (lum/f^2)	Internal Intensity (lum/m^2)	Internal Voltage (V)	Internal CO_2 Concentration (ppm)
11:00	07/15/06 11:00	22.09	29.10	41.7	30.7	8.1	6.8	8.9	7.4	46	4	0.532	532
	07/15/06 11:12	22.09	31.93	41.3	25.1	8.1	6.8	8.5	7.1	46	4	0.552	552
	07/15/06 11:24	22.09	33.17	40.8	25.0	8.0	6.7	9.0	7.5	44	4	0.581	581
	07/15/06 11:36	22.09	34.43	40.5	24.0	7.9	6.6	9.2	7.7	44	4	0.591	591
	07/15/06 11:48	22.48	34.01	40.0	24.2	8.0	6.7	9.1	7.6	54	5	0.601	601
12:00	07/15/06 12:00	22.48	34.43	39.4	24.1	7.8	6.5	9.3	7.8	56	5	0.601	601
	07/15/06 12:12	22.48	34.43	38.8	24.0	7.7	6.4	9.2	7.7	66	6	0.640	640
	07/15/06 12:24	22.48	33.59	38.1	24.7	7.6	6.3	9.1	7.6	64	6	0.620	620
	07/15/06 12:36	22.86	30.31	38.6	26.6	7.9	6.6	8.2	6.8	76	7	0.649	649
	07/15/06 12:48	22.86	23.24	37.5	39.2	7.6	6.3	8.2	6.8	91	8	0.640	640
13:00	07/15/06 13:00	23.24	22.09	37.5	42.9	7.8	6.5	8.4	7.0	103	10	0.679	679
	07/15/06 13:12	25.17	21.33	33.9	45.1	7.9	6.6	8.4	7.0	634	59	0.659	659
	07/15/06 13:24	25.95	21.71	29.6	45.8	7.2	6.0	8.7	7.3	634	59	0.669	669
	07/15/06 13:36	25.17	21.33	31.3	45.4	7.3	6.1	8.5	7.1	522	48	0.679	679
	07/15/06 13:48	26.34	21.33	29.2	45.2	7.2	6.0	8.4	7.0	467	43	0.688	688
14:00	07/15/06 14:00	27.12	21.33	28.6	46.2	7.4	6.2	8.6	7.2	604	56	0.718	718
	07/15/06 14:12	27.91	21.33	26.9	46.6	7.3	6.1	8.7	7.3	634	59	0.718	718
	07/15/06 14:24	25.56	20.95	29.9	47.3	7.1	5.9	8.6	7.2	210	20	0.718	718
	07/15/06 14:36	26.34	20.95	31.1	46.7	7.7	6.4	8.5	7.1	634	59	0.718	718
	07/15/06 14:48	27.91	21.33	27.4	45.6	7.4	6.2	8.5	7.1	634	59	0.718	718
15:00	07/15/06 15:00	28.70	21.33	25.9	45.1	7.3	6.1	8.4	7.0	634	59	0.737	737
	07/15/06 15:12	28.31	21.33	25.2	40.0	7.0	5.8	7.5	6.3	529	49	0.698	698
	07/15/06 15:24	27.12	21.33	26.4	36.4	6.8	5.7	6.8	5.7	442	41	0.737	737
	07/15/06 15:36	27.91	21.71	25.3	34.4	6.8	5.7	6.6	5.5	552	51	0.747	747
	07/15/06 15:48	27.91	21.33	24.8	42.5	6.7	5.6	7.9	6.6	432	40	0.747	747
16:00	07/15/06 16:00	27.91	21.33	25.5	41.2	6.9	5.8	7.7	6.4	420	39	0.737	737
	07/15/06 16:12	26.34	21.33	26.8	43.6	6.6	5.5	8.1	6.8	118	11	0.737	737
	07/15/06 16:24	25.17	21.33	29.9	43.1	6.9	5.8	8.0	6.7	68	6	0.737	737
	07/15/06 16:36	24.79	20.95	31.2	42.8	7.1	5.9	7.8	6.5	64	6	0.708	708
	07/15/06 16:48	24.40	20.95	31.9	43.3	7.1	5.9	7.9	6.6	46	4	0.708	708
17:00	07/15/06 17:00	24.40	20.95	32.2	44.8	7.2	6.0	8.2	6.8	49	5	0.708	708
	07/15/06 17:12	24.01	20.57	33.0	44.2	7.2	6.0	7.9	6.6	49	5	0.708	708
	07/15/06 17:24	24.01	20.57	33.0	45.1	7.2	6.0	8.0	6.7	41	4	0.708	708
	07/15/06 17:36	23.63	20.19	33.6	46.4	7.2	6.0	8.1	6.8	36	3	0.688	688
	07/15/06 17:48	23.63	20.19	33.9	48.0	7.2	6.0	8.4	7.0	34	3	0.659	659
18:00	07/15/06 18:00	23.63	20.19	34.7	49.5	7.4	6.2	8.6	7.2	41	4	0.649	649
Average		24.91	24.11	32.7	39.3	7.4	6.1	8.3	6.9	256	24	0.677	677
	07/15/06 18:12	23.24		34.9		7.3	6.1			34	3	0.649	649
	07/15/06 18:24	23.24		34.5		7.2	6.0			31	3	0.640	640
	07/15/06 18:36	23.24		35.4		7.4	6.2			26	2	0.630	630
	07/15/06 18:48	22.86		35.8		7.3	6.1			31	3	0.669	669

Hour	Date/Time	Internal Temperature (°C)	External Temperature (°C)	Internal RH (%)	External RH (%)	Internal Absolute Humidity (g/m^3)	Internal Absolute Humidity (g/kg)	External Absolute Humidity (g/m^3)	External Absolute Humidity (g/kg)	Internal Intensity (lum/f^2)	Internal Intensity (lum/m^2)	Internal Voltage (V)	Internal CO_2 Concentration (ppm)
19:00	07/15/06 19:00	22.86		36.2		7.4	6.2			24	2	0.708	708
	07/15/06 19:12	23.24		36.8		7.7	6.4			29	3	0.698	698
	07/15/06 19:24	23.63		36.2		7.7	6.4			24	2	0.776	776
	07/15/06 19:36	23.24		35.4		7.4	6.2			24	2	0.767	767
	07/15/06 19:48	23.63		35.1		7.5	6.3			11	1	0.679	679
20:00	07/15/06 20:00	24.01		35.7		7.8	6.5			6	1	0.659	659
	07/15/06 20:12	24.01		35.6		7.7	6.4			9	1	0.571	571
	07/15/06 20:24	24.01		35.7		7.8	6.5			9	1	0.552	552
	07/15/06 20:36	24.01		35.8		7.8	6.5			6	1	0.542	542
	07/15/06 20:48	24.01		36.8		8.0	6.7			4	0	0.532	532
21:00	07/15/06 21:00	24.01		36.1		7.9	6.6			1	0	0.542	542
	07/15/06 21:12	24.01		36.3		7.9	6.6			1	0	0.513	513
	07/15/06 21:24	23.63		36.1		7.7	6.4			1	0	0.513	513
	07/15/06 21:36	23.63		36.7		7.8	6.5			1	0	0.513	513
	07/15/06 21:48	23.63		37.6		8.0	6.7			1	0	0.532	532
22:00	07/15/06 22:00	23.63		38.3		8.2	6.8			1	0	0.552	552
	07/15/06 22:12	23.63		38.7		8.2	6.8			1	0	0.532	532
	07/15/06 22:24	23.63		38.6		8.2	6.8			1	0	0.522	522
	07/15/06 22:36	23.63		38.2		8.1	6.8			1	0	0.503	503
	07/15/06 22:48	23.63		38.3		8.2	6.8			1	0	0.493	493
23:00	07/15/06 23:00	23.63		38.0		8.1	6.8			4	0	0.483	483
	07/15/06 23:12	23.63		38.8		8.3	6.9			4	0	0.503	503
	07/15/06 23:24	23.63		38.6		8.2	6.8			1	0	0.483	483
	07/15/06 23:36	23.63		39.2		8.4	7.0			4	0	0.483	483
	07/15/06 23:48	23.63		38.3		8.2	6.8			4	0	0.493	493
00:00	07/16/06 00:00	23.63		38.3		8.2	6.8			4	0	0.493	493
	07/16/06 00:12	23.63		38.6		8.2	6.8			4	0	0.493	493
	07/16/06 00:24	23.63		38.3		8.2	6.8			4	0	0.483	483
	07/16/06 00:36	23.24		38.7		8.1	6.8			1	0	0.483	483
	07/16/06 00:48	23.63		38.8		8.3	6.9			1	0	0.483	483
01:00	07/16/06 01:00	23.24		39.5		8.2	6.8			1	0	0.483	483
	07/16/06 01:12	23.24		39.4		8.2	6.8			4	0	0.483	483
	07/16/06 01:24	23.24		39.6		8.3	6.9			4	0	0.474	474
	07/16/06 01:36	23.24		39.9		8.3	6.9			4	0	0.474	474
	07/16/06 01:48	23.24		40.3		8.4	7.0			1	0	0.474	474
02:00	07/16/06 02:00	23.24		40.2		8.4	7.0			1	0	0.474	474
	07/16/06 02:12	23.24		40.3		8.4	7.0			1	0	0.464	464
	07/16/06 02:24	23.24		40.4		8.4	7.0			1	0	0.464	464
	07/16/06 02:36	23.24		40.4		8.4	7.0			1	0	0.464	464
	07/16/06 02:48	23.24		40.3		8.4	7.0			1	0	0.464	464
03:00	07/16/06 03:00	22.86		40.3		8.2	6.8			1	0	0.474	474
	07/16/06 03:12	22.86		40.4		8.2	6.8			4	0	0.474	474
	07/16/06 03:24	22.86		40.4		8.2	6.8			1	0	0.474	474
	07/16/06 03:36	22.86		40.3		8.2	6.8			4	0	0.474	474
	07/16/06 03:48	22.86		40.4		8.2	6.8			4	0	0.474	474

Hour	Date/Time	Internal Temperature (°C)	External Temperature (°C)	Internal RH (%)	External RH (%)	Internal Absolute Humidity (g/m^3)	Internal Absolute Humidity (g/kg)	External Absolute Humidity (g/m^3)	External Absolute Humidity (g/kg)	Internal Intensity (lum/f^2)	Internal Intensity (lum/m^2)	Internal Voltage (V)	Internal CO_2 Concentration (ppm)
04:00	07/16/06 04:00	22.86		40.3		8.2	6.8			1	0	0.464	464
	07/16/06 04:12	22.86		40.4		8.2	6.8			1	0	0.464	464
	07/16/06 04:24	22.86		40.4		8.2	6.8			1	0	0.454	454
	07/16/06 04:36	22.86		40.6		8.3	6.9			4	0	0.464	464
	07/16/06 04:48	22.48		41.1		8.2	6.8			4	0	0.464	464
05:00	07/16/06 05:00	22.48		41.3		8.2	6.8			1	0	0.464	464
	07/16/06 05:12	22.48		42.1		8.4	7.0			4	0	0.464	464
	07/16/06 05:24	22.48		41.9		8.3	6.9			4	0	0.454	454
	07/16/06 05:36	22.48		42.1		8.4	7.0			4	0	0.464	464
	07/16/06 05:48	22.48		42.7		8.5	7.1			6	1	0.464	464
06:00	07/16/06 06:00	22.48		42.4		8.5	7.1			6	1	0.464	464
	07/16/06 06:12	22.48		42.8		8.5	7.1			9	1	0.464	464
	07/16/06 06:24	22.48		43.2		8.6	7.2			9	1	0.464	464
	07/16/06 06:36	22.48		42.0		8.4	7.0			14	1	0.464	464
	07/16/06 06:48	22.48		41.6		8.3	6.9			9	1	0.464	464
07:00	07/16/06 07:00	22.86		41.4		8.4	7.0			9	1	0.454	454
	07/16/06 07:12	22.86		41.5		8.5	7.1			14	1	0.464	464
	07/16/06 07:24	22.86		41.7		8.5	7.1			9	1	0.464	464
	07/16/06 07:36	22.86		41.9		8.5	7.1			14	1	0.454	454
	07/16/06 07:48	22.86		42.9		8.8	7.3			19	2	0.454	454
08:00	07/16/06 08:00	22.86		42.4		8.6	7.2			14	1	0.454	454
	07/16/06 08:12	22.86		43.4		8.8	7.3			21	2	0.454	454
	07/16/06 08:24	23.24		43.4		9.0	7.5			19	2	0.454	454
	07/16/06 08:36	23.24		43.5		9.1	7.6			26	2	0.454	454
	07/16/06 08:48	23.24		44.0		9.2	7.7			26	2	0.454	454
09:00	07/16/06 09:00	23.24		43.5		9.1	7.6			24	2	0.454	454
	07/16/06 09:12	23.24		43.5		9.1	7.6			21	2	0.444	444
	07/16/06 09:24	23.63		43.6		9.3	7.8			29	3	0.444	444
	07/16/06 09:36	23.63		44.1		9.4	7.8			31	3	0.464	464
	07/16/06 09:48	23.63		45.3		9.6	8.0			31	3	0.435	435
10:00	07/16/06 10:00	23.24		43.4		9.0	7.5			26	2	0.444	444
	07/16/06 10:12	22.86		44.2		9.0	7.5			26	2	0.435	435
	07/16/06 10:24	22.86		46.1		9.4	7.8			36	3	0.444	444
	07/16/06 10:36	22.48		46.0		9.2	7.7			39	4	0.464	464
	07/16/06 10:48	22.86		45.8		9.3	7.8			49	5	0.483	483
11:00	07/16/06 11:00	22.86		44.4		9.1	7.6			46	4	0.513	513
Average		23.20		40.0		8.3	6.9			11	1	0.503	503
Average		24.05		36.3		7.8	6.5			134	12	0.590	590

Appendix F.3. Charts of the profiles of the environmental parameters during the occupants' survey

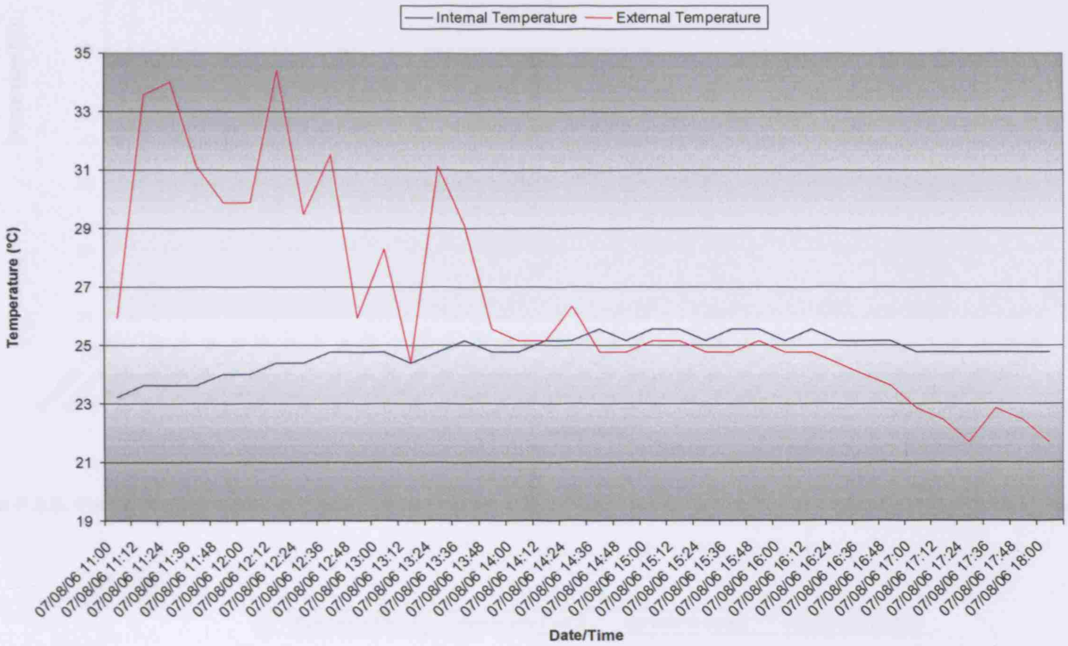


Figure F.3.1. Profile of the internal and external temperature during the survey in Thecentre:mk.

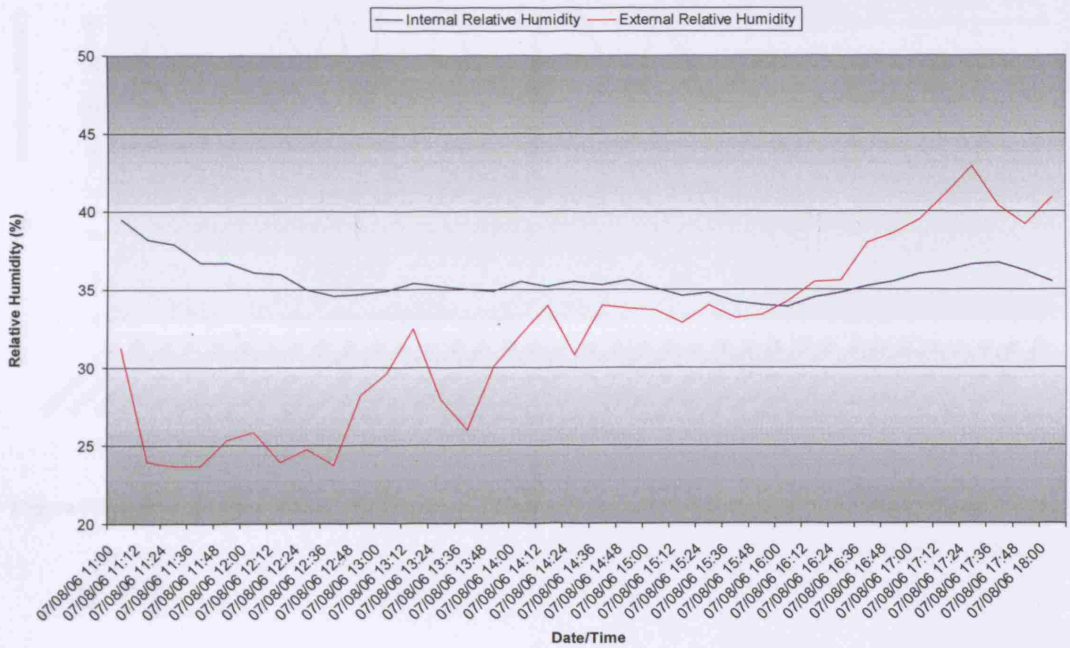


Figure F.3.2. Profile of the internal and external relative humidity during the occupants' survey in Thecentre:mk.

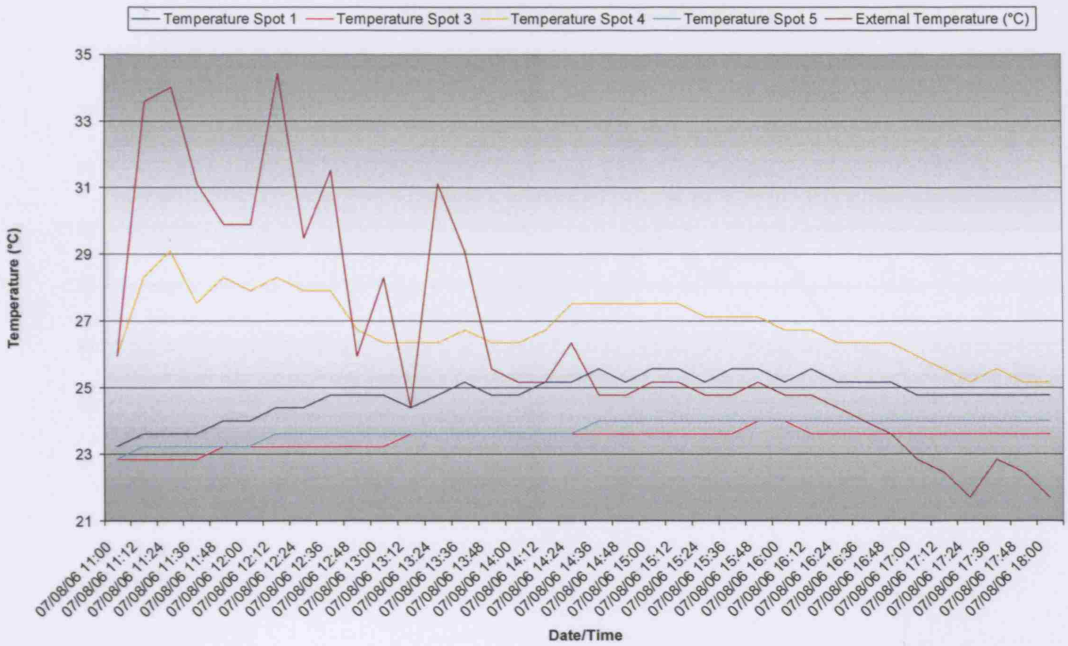


Figure F.3.3. Profile of the internal and external temperature in different areas during the occupants' survey in Thecentre:mk.

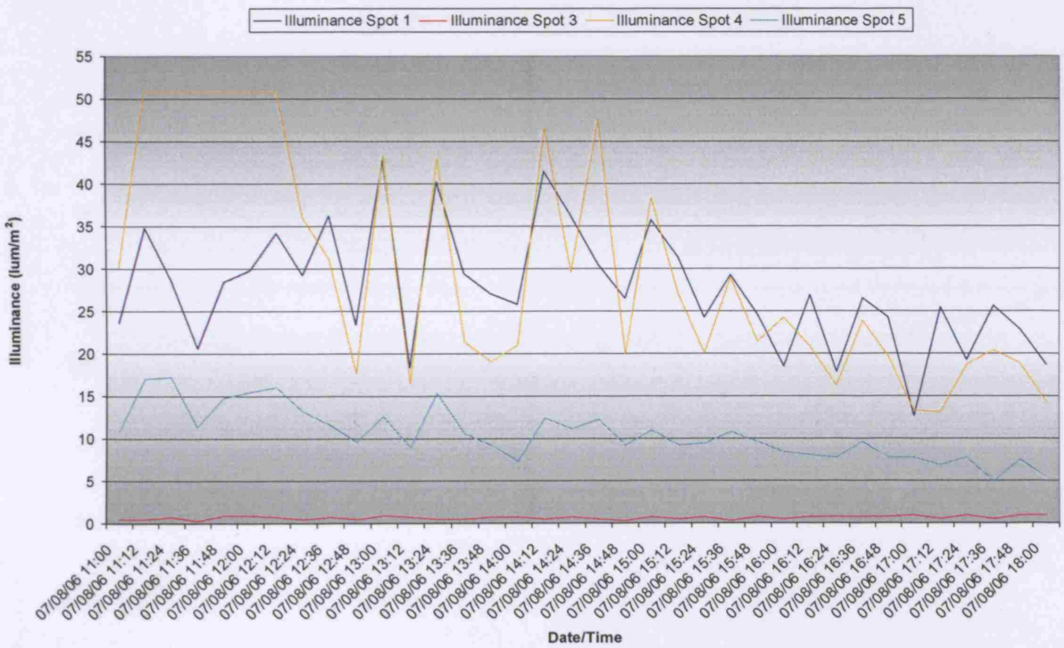


Figure F.3.4. Profile of the internal illuminance in different areas during the occupants' survey in Thecentre:mk.

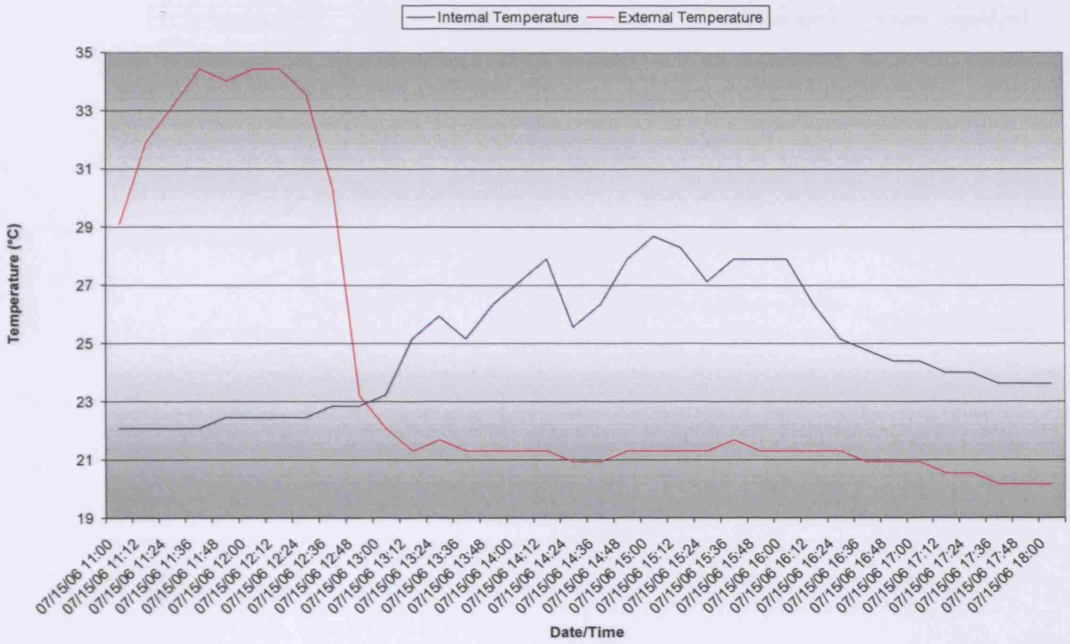


Figure F.3.5. Profile of the internal and external temperature during the occupants' survey in Lakeside Shopping Centre.

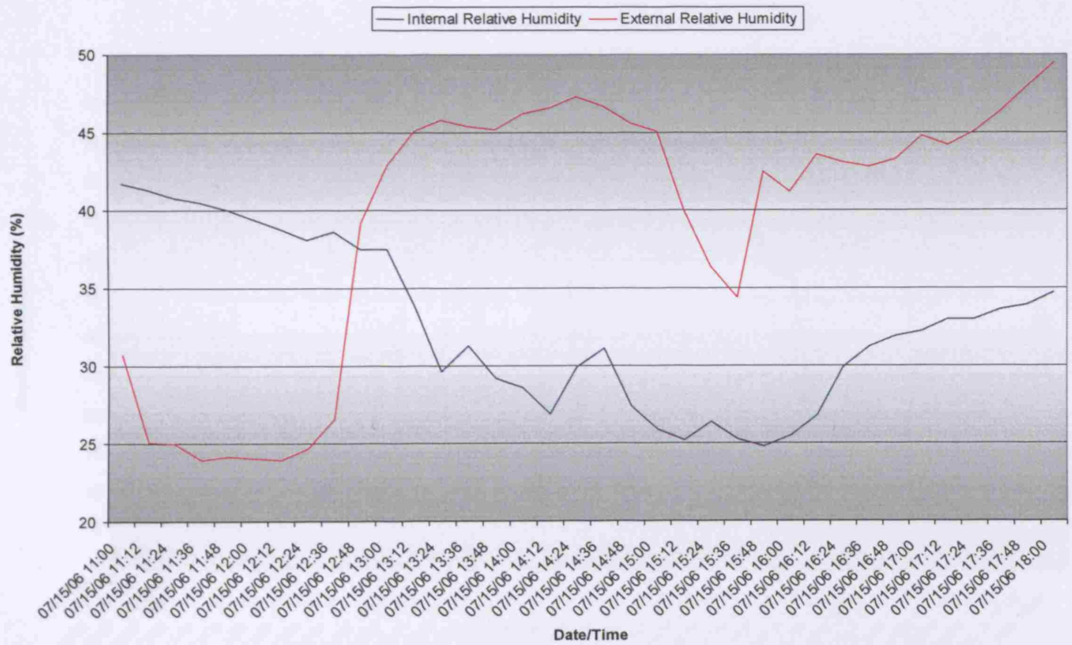


Figure F.3.6. Profile of the internal and external relative humidity during the occupants' survey in Lakeside Shopping Centre.

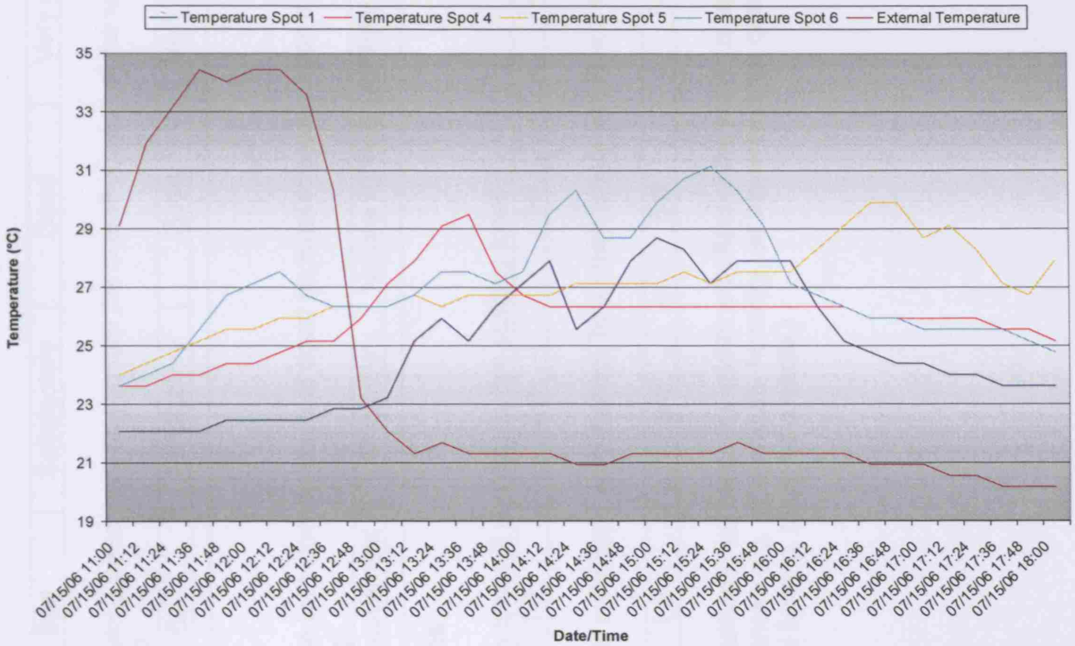


Figure F.3.7. Profile of the internal and external temperature in different areas during the occupants' survey in Lakeside Shopping Centre.

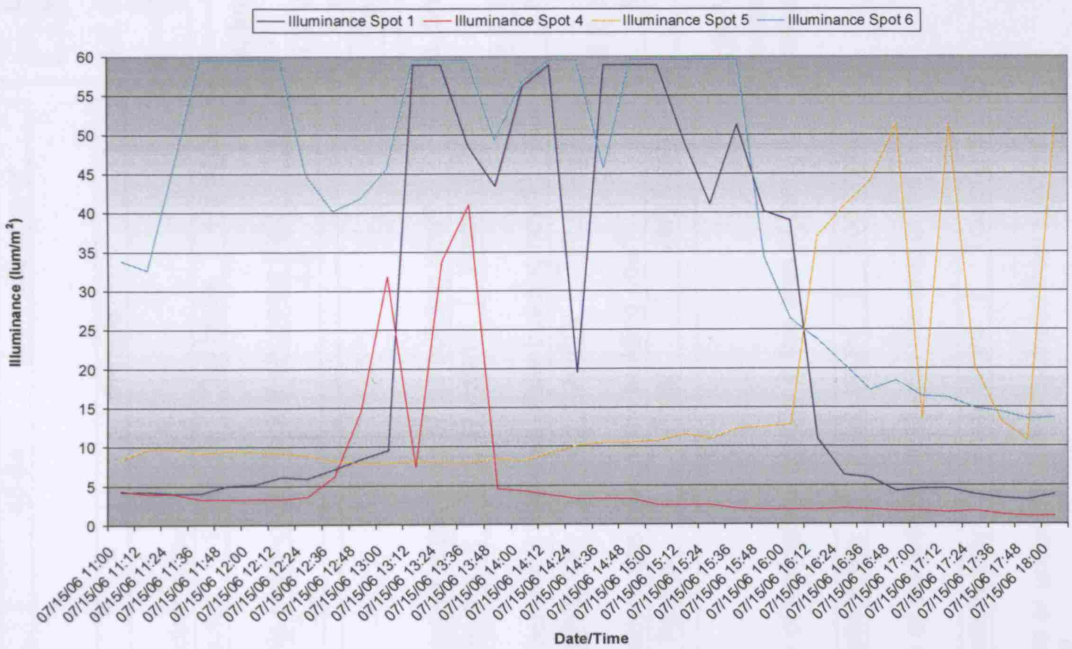


Figure F.3.8. Profile of the internal illuminance in different areas during the occupants' survey in Lakeside Shopping Centre.

ID: Time:

Shopping Centre Survey of Shoppers (2006)

1. Background

1.1. What is your age?

18-24	25-44	45-64	65 or over

1.2. What is your gender?

Male	Female

1.3. How long have you been in this building today?

Less than 30 minutes	30-60 minutes	1-2 hours	2-4 hours	4-6 hours

1.4. How many hours do you spend in this building on a typical shopping trip?

0-2	2-4	4-8

2. Thermal comfort

2.1. How would you describe the *temperature* in this area of the building now?

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

2.2. How would you describe the *air movement* in this area of the building now?

Too still	Fairly still	Satisfactory	Fairly draughty	Too draughty

2.3. How would you describe the *air quality* in this area of the building now?

Very stuffy	Stuffy	Neutral	Fresh	Very fresh

3. Lighting

3.1. How would you describe the quality of the *natural lighting* in this area of the building now?

Too dim	Fairly dim	Satisfactory	Fairly bright	Too bright

3.2. How would you describe the quality of the *artificial lighting* in this area of the building now?

Too dim	Fairly dim	Satisfactory	Fairly bright	Too bright

3.3. How do you rate the amount of *glare or uncomfortable brightness from sun and sky* in this area of the building now?

None	Occasional	Moderate	Considerable	Continuous

3.4. How do you rate the amount of *glare or uncomfortable brightness from lights* in this area of the building now?

None	Occasional	Moderate	Considerable	Continuous

4. Overall comfort

4.1. All things considered, how do you rate the overall comfort of this area of the building now?

Very bad	Bad	Satisfactory	Good	Very good

4.2. Based on your previous visits, how do you rate the overall comfort of the whole building in general?

Very bad	Bad	Satisfactory	Good	Very good

5. Improvement

5.1. Which item(s) of the list below do you feel could be most improved upon in this area of the building?

Temperature	Air movement	Air quality	Natural lighting	Artificial lighting

6. Shopping conditions

6.1. How many hours in total will you stay in this building today?

Less than 1	1-2	3-4	5-6	7-8

6.2. If the environmental conditions were perfect, how much longer would you stay in this building?

0	1-2	3-4	5-6	7-8

(By "environmental conditions" we mean the combined effect of the previous topics covered in the questionnaire e.g. temperature, humidity, air movement, air quality, natural lighting, artificial lighting, taken as a whole.)

SPECIAL NOTE

THIS ITEM IS BOUND IN SUCH A MANNER AND WHILE EVERY EFFORT HAS BEEN MADE TO REPRODUCE THE CENTRES, FORCE WOULD RESULT IN DAMAGE

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45-64	65 or over

Female

y?

	1-2 hours	2-4 hours	4-6 hours

in this shop now?

	Slightly warm	Warm	Hot

t in this shop now?

ory	Fairly draughty	Too draughty

this shop now?

al	Fresh	Very fresh

natural lighting in this shop now?

ory	Fairly bright	Too bright

artificial lighting in this shop now?

ory	Fairly bright	Too bright

ncomfortable brightness from sun and

te	Considerable	Continuous

ncomfortable brightness from lights in

te	Considerable	Continuous

overall comfort of this shop now?

ory	Good	Very good

4.2. Based on your experience, how do you rate the overall comfort of the whole building in general?

Very bad	Bad	Satisfactory	Good	Very good

5. Personal control

5.1. How much control do you personally have over *heating* in this shop?

None	Limited	Moderate	Considerable	Full

5.2. How much control do you personally have over *cooling* in this shop?

None	Limited	Moderate	Considerable	Full

5.3. How much control do you personally have over *ventilation* in this shop?

None	Limited	Moderate	Considerable	Full

5.4. How much control do you personally have over *natural lighting* in this shop?

None	Limited	Moderate	Considerable	Full

5.5. How much control do you personally have over *artificial lighting* in this shop?

None	Limited	Moderate	Considerable	Full

6. Energy issue

6.1. Are you concerned about saving energy in this shop?

Not at all	Slightly	Moderately	Very	Fully

7. Improvement

7.1. Which item(s) of the list below do you feel could be most improved upon in this shop?

Temperature	Air movement	Air quality	Natural lighting	Artificial lighting

8. Shopping and working conditions

8.1. How do you rate the environmental conditions in this shop for *shopping*?

Very bad	Bad	Satisfactory	Good	Very good

(By "environmental conditions" we mean the combined effect of the previous topics covered in the questionnaire e.g. temperature, humidity, air movement, air quality, natural lighting, artificial lighting, taken as a whole.)

8.2. How do you rate the environmental conditions in this shop for *working*?

Very bad	Bad	Satisfactory	Good	Very good

SPECIAL NOTE

THIS ITEM IS BOUND IN SUCH A MANNER AND WHILE EVERY EFFORT HAS BEEN MADE TO REPRODUCE THE CENTRES, FORCE WOULD RESULT IN DAMAGE

3	4

F

day?

4	5

ding on a typical shopping trip?

3

in this area of the building now?

1	2	3

t in this area of the building now?

1	2

this area of the building now?

1	2

natural lighting in this area of the

1	2

artificial lighting in this area of the

1	2

ncomfortable brightness from sun and

3	4

ncomfortable brightness from lights in

3	4

4. Overall comfort

4.1. All things considered, how do you rate the overall comfort of this area of the building now?

-2	-1	0	1	2

4.2. Based on your previous visits, how do you rate the overall comfort of the whole building in general?

-2	-1	0	1	2

5. Improvement

5.1. Which item(s) of the list below do you feel could be most improved upon in this area of the building?

T.	A.M.	A.Q.	N.L.	A.L.

6. Shopping conditions

6.1. How many hours in total will you stay in this building today?

1	2	3	4	5

6.2. If the environmental conditions were perfect, how much longer would you stay in this building?

0	1	2	3	4

(By "environmental conditions" we mean the combined effect of the previous topics covered in the questionnaire e.g. temperature, humidity, air movement, air quality, natural lighting, artificial lighting, taken as a whole.)

SPECIAL NOTE

THIS ITEM IS BOUND IN SUCH A MANNER AND WHILE EVERY EFFORT HAS BEEN MADE TO REPRODUCE THE CENTRES, FORCE WOULD RESULT IN DAMAGE

Shopping Centre Survey of Tenants (2006) – Questionnaire for Coding Purposes

1. Background

1.1. What is your age?

1	2	3	4

1.2. What is your gender?

M	F

1.3. How long have you been in this shop today?

1	2	3	4	5

2. Thermal comfort

2.1. How would you describe the *temperature* in this shop now?

-3	-2	-1	0	1	2	3

2.2. How would you describe the *air movement* in this shop now?

-2	-1	0	1	2

2.3. How would you describe the *air quality* in this shop now?

-2	-1	0	1	2

3. Lighting

3.1. How would you describe the quality of the *natural lighting* in this shop now?

-2	-1	0	1	2

3.2. How would you describe the quality of the *artificial lighting* in this shop now?

-2	-1	0	1	2

3.3. How do you rate the amount of *glare or uncomfortable brightness from sun and sky* in this shop now?

0	1	2	3	4

3.4. How do you rate the amount of *glare or uncomfortable brightness from lights* in this shop now?

0	1	2	3	4

4. Overall comfort

4.1. All things considered, how do you rate the overall comfort of this shop now?

-2	-1	0	1	2

4.2. Based on your experience, how do you rate the overall comfort of the whole building in general?

-2	-1	0	1	2

5. Personal control

5.1. How much control do you personally have over *heating* in this shop?

0	1	2	3	4

5.2. How much control do you personally have over *cooling* in this shop?

0	1	2	3	4

5.3. How much control do you personally have over *ventilation* in this shop?

0	1	2	3	4

5.4. How much control do you personally have over *natural lighting* in this shop?

0	1	2	3	4

5.5. How much control do you personally have over *artificial lighting* in this shop?

0	1	2	3	4

6. Energy issue

6.1. Are you concerned about saving energy in this shop?

0	1	2	3	4

7. Improvement

7.1. Which item(s) of the list below do you feel could be most improved upon in this shop?

T.	A.M.	A.Q.	N.L.	A.L.

8. Shopping and working conditions

8.1. How do you rate the environmental conditions in this shop for *shopping*?

-2	-1	0	1	2

(By "environmental conditions" we mean the combined effect of the previous topics covered in the questionnaire e.g. temperature, humidity, air movement, air quality, natural lighting, artificial lighting, taken as a whole.)

8.2. How do you rate the environmental conditions in this shop for *working*?

-2	-1	0	1	2

Appendix G.5. Results of the shopping centre survey of shoppers (2006)

Question 1.1						
Age	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
18-24	6	12%	7	14%	13	13%
25-44	22	44%	26	52%	48	48%
45-64	19	38%	15	30%	34	34%
65 or over	3	6%	2	4%	5	5%

Question 1.2						
Gender	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Male	28	56%	23	46%	51	51%
Female	22	44%	27	54%	49	49%

Question 1.3						
Time in Building	Thecentre:mk		Lakeside		Overall Total	
till Survey Moment	Number	Percentage	Number	Percentage	Number	Percentage
Less than 30 minutes	4	8%	5	10%	9	9%
30-60 minutes	9	18%	11	22%	20	20%
1-2 hours	24	48%	24	48%	48	48%
2-4 hours	12	24%	7	14%	19	19%
4-6 hours	1	2%	3	6%	4	4%

Question 1.4						
Hours in Building	Thecentre:mk		Lakeside		Overall Total	
on Typical Shopping Trip	Number	Percentage	Number	Percentage	Number	Percentage
0-2	16	32%	11	22%	27	27%
2-4	27	54%	28	56%	55	55%
4-8	7	14%	11	22%	18	18%

Question 2.1						
Temperature	Thecentre:mk		Lakeside		Overall Total	
in Survey Area	Number	Percentage	Number	Percentage	Number	Percentage
Cold	0	0%	0	0%	0	0%
Cool	2	4%	7	14%	9	9%
Slightly cool	6	12%	9	18%	15	15%
Neutral	27	54%	25	50%	52	52%
Slightly warm	14	28%	5	10%	19	19%
Warm	1	2%	3	6%	4	4%
Hot	0	0%	1	2%	1	1%

Question 2.2						
Air Movement	Thecentre:mk		Lakeside		Overall Total	
in Survey Area	Number	Percentage	Number	Percentage	Number	Percentage
Too still	2	4%	0	0%	2	2%
Fairly still	16	32%	4	8%	20	20%
Satisfactory	32	64%	46	92%	78	78%
Fairly draughty	0	0%	0	0%	0	0%
Too draughty	0	0%	0	0%	0	0%

Question 2.3						
Air Quality	Thecentre:mk		Lakeside		Overall Total	
in Survey Area	Number	Percentage	Number	Percentage	Number	Percentage
Very stuffy	0	0%	0	0%	0	0%
Stuffy	4	8%	6	12%	10	10%
Neutral	30	60%	35	70%	65	65%
Fresh	15	30%	9	18%	24	24%
Very fresh	1	2%	0	0%	1	1%

Question 3.1						
Natural Lighting Quality in Survey Area	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Too dim	0	0%	1	2%	1	1%
Fairly dim	0	0%	5	10%	5	5%
Satisfactory	32	64%	29	58%	61	61%
Fairly bright	18	36%	14	28%	32	32%
Too bright	0	0%	1	2%	1	1%

Question 3.2						
Artificial Lighting Quality in Survey Area	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Too dim	0	0%	0	0%	0	0%
Fairly dim	3	6%	3	6%	6	6%
Satisfactory	43	86%	34	68%	77	77%
Fairly bright	3	6%	10	20%	13	13%
Too bright	1	2%	3	6%	4	4%

Question 3.3						
Glare or Uncomfortable Brightness from Sun and Sky in Survey Area	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
None	28	56%	21	42%	49	49%
Occasional	12	24%	17	34%	29	29%
Moderate	7	14%	10	20%	17	17%
Considerable	2	4%	2	4%	4	4%
Continuous	1	2%	0	0%	1	1%

Question 3.4						
Glare or Uncomfortable Brightness from Lights in Survey Area	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
None	37	74%	27	54%	64	64%
Occasional	7	14%	9	18%	16	16%
Moderate	6	12%	12	24%	18	18%
Considerable	0	0%	2	4%	2	2%
Continuous	0	0%	0	0%	0	0%

Question 4.1						
Overall Comfort of Survey Area	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Very bad	0	0%	0	0%	0	0%
Bad	0	0%	0	0%	0	0%
Satisfactory	19	38%	26	52%	45	45%
Good	29	58%	23	46%	52	52%
Very good	2	4%	1	2%	3	3%

Question 4.2						
Overall Comfort of Whole Building	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Very bad	0	0%	0	0%	0	0%
Bad	1	2%	0	0%	1	1%
Satisfactory	17	34%	23	46%	40	40%
Good	27	54%	21	42%	48	48%
Very good	5	10%	6	12%	11	11%

Question 5.1						
Improvements in Survey Area	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Temperature	11	19	11	22	22	20
Air movement	19	33	11	22	30	28
Air quality	10	18	7	14	17	16
Natural lighting	3	5	12	24	15	14
Artificial lightig	8	14	2	4	10	9
None	6	11	8	16	14	13

Question 6.1						
Total Hours in Building during Survey Day	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Less than 1	3	6%	3	6%	6	6%
1-2	14	28%	16	32%	30	30%
3-4	28	56%	21	42%	49	49%
5-6	5	10%	9	18%	14	14%
7-8	0	0%	1	2%	1	1%

Question 6.2						
Additional Hours in Building if Perfect Environmental Conditions	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
0	33	66%	38	76%	71	71%
1-2	12	24%	8	16%	20	20%
3-4	4	8%	2	4%	6	6%
5-6	1	2%	1	2%	2	2%
7-8	0	0%	1	2%	1	1%

Appendix G.6. Results of the shopping centre survey of tenants (2006)

Question 1.1						
Age	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
18-24	20	59%	26	68%	46	64%
25-44	12	35%	10	26%	22	31%
45-64	2	6%	2	5%	4	6%
65 or over	0	0%	0	0%	0	0%

Question 1.2						
Gender	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Male	9	26%	19	50%	28	39%
Female	25	74%	19	50%	44	61%

Question 1.3						
Time in Building till Survey Moment	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Less than 30 minutes	0	0%	5	13%	5	7%
30-60 minutes	2	6%	1	3%	3	4%
1-2 hours	3	9%	3	8%	6	8%
2-4 hours	10	29%	12	32%	22	31%
4-6 hours	19	56%	17	45%	36	50%

Question 2.1						
Temperature in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Cold	0	0%	1	3%	1	1%
Cool	6	18%	8	21%	14	19%
Slightly cool	10	29%	6	16%	16	22%
Neutral	9	26%	11	29%	20	28%
Slightly warm	4	12%	10	26%	14	19%
Warm	5	15%	2	5%	7	10%
Hot	0	0%	0	0%	0	0%

Question 2.2						
Air Movement in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Too still	1	3%	3	8%	4	6%
Fairly still	8	24%	11	29%	19	26%
Satisfactory	22	65%	21	55%	43	60%
Fairly draughty	3	9%	3	8%	6	8%
Too draughty	0	0%	0	0%	0	0%

Question 2.3						
Air Quality in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Very stuffy	0	0%	0	0%	0	0%
Stuffy	5	15%	7	18%	12	17%
Neutral	18	53%	26	68%	44	61%
Fresh	11	32%	5	13%	16	22%
Very fresh	0	0%	0	0%	0	0%

Question 3.1						
Natural Lighting Quality in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Too dim	6	18%	23	61%	29	40%
Fairly dim	4	12%	3	8%	7	10%
Satisfactory	18	53%	6	16%	24	33%
Fairly bright	4	12%	4	11%	8	11%
Too bright	2	6%	2	5%	4	6%

Question 3.2						
Artificial Lighting Quality in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Too dim	1	3%	1	3%	2	3%
Fairly dim	1	3%	4	11%	5	7%
Satisfactory	22	65%	18	47%	40	56%
Fairly bright	8	24%	11	29%	19	26%
Too bright	2	6%	4	11%	6	8%

Question 3.3						
Glare or Uncomfortable Brightness from Sun and Sky in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
None	20	59%	35	92%	55	76%
Occasional	8	24%	1	3%	9	13%
Moderate	4	12%	2	5%	6	8%
Considerable	2	6%	0	0%	2	3%
Continuous	0	0%	0	0%	0	0%

Question 3.4						
Glare or Uncomfortable Brightness from Lights in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
None	17	50%	16	42%	33	46%
Occasional	9	26%	16	42%	25	35%
Moderate	6	18%	4	11%	10	14%
Considerable	2	6%	1	3%	3	4%
Continuous	0	0%	1	3%	1	1%

Question 4.1						
Overall Comfort of Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Very bad	0	0%	0	0%	0	0%
Bad	0	0%	2	5%	2	3%
Satisfactory	17	50%	19	50%	36	50%
Good	11	32%	15	39%	26	36%
Very good	6	18%	2	5%	8	11%

Question 4.2						
Overall Comfort of Whole Building	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Very bad	0	0%	0	0%	0	0%
Bad	3	9%	3	8%	6	8%
Satisfactory	20	59%	16	42%	36	50%
Good	9	26%	19	50%	28	39%
Very good	2	6%	0	0%	2	3%

Question 5.1						
Personal Control over Heating in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
None	7	21%	13	34%	20	28%
Limited	6	18%	2	5%	8	11%
Moderate	5	15%	2	5%	7	10%
Considerable	9	26%	4	11%	13	18%
Full	7	21%	17	45%	24	33%

Question 5.2						
Personal Control over Cooling in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
None	9	26%	13	34%	22	31%
Limited	4	12%	2	5%	6	8%
Moderate	5	15%	3	8%	8	11%
Considerable	9	26%	3	8%	12	17%
Full	7	21%	17	45%	24	33%

Question 5.3						
Personal Control over Ventilation in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
None	13	38%	16	42%	29	40%
Limited	5	15%	2	5%	7	10%
Moderate	5	15%	3	8%	8	11%
Considerable	5	15%	3	8%	8	11%
Full	6	18%	14	37%	20	28%

Question 5.4						
Personal Control over Natutal Lighting in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
None	25	74%	33	87%	58	81%
Limited	6	18%	1	3%	7	10%
Moderate	3	9%	1	3%	4	6%
Considerable	0	0%	3	8%	3	4%
Full	0	0%	0	0%	0	0%

Question 5.5						
Personal Control over Artificial Lighting in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
None	12	35%	18	47%	30	42%
Limited	8	24%	3	8%	11	15%
Moderate	3	9%	0	0%	3	4%
Considerable	4	12%	2	5%	6	8%
Full	7	21%	15	39%	22	31%

Question 6.1						
Concern about Saving Energy in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Not at all	8	24%	15	39%	23	32%
Slightly	9	26%	13	34%	22	31%
Moderately	9	26%	6	16%	15	21%
Very	4	12%	1	3%	5	7%
Fully	4	12%	3	8%	7	10%

Question 7.1						
Improvements in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Temperature	13	33	17	36	30	35
Air movement	4	10	6	13	10	12
Air quality	7	18	14	30	21	24
Natural lighting	9	23	3	6	12	14
Artificial lightig	5	13	6	13	11	13
None	1	3	1	2	2	2

Question 8.1						
Shopping Conditions in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Very bad	0	0%	1	3%	1	1%
Bad	1	3%	1	3%	2	3%
Satisfactory	14	41%	15	39%	29	40%
Good	16	47%	18	47%	34	47%
Very good	3	9%	3	8%	6	8%

Question 8.2						
Working Conditions in Shop	Thecentre:mk		Lakeside		Overall Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Very bad	0	0%	1	3%	1	1%
Bad	1	3%	4	11%	5	7%
Satisfactory	14	41%	7	18%	21	29%
Good	14	41%	24	63%	38	53%
Very good	5	15%	2	5%	7	10%

Appendix G.7. Analysis of the responses of shoppers

1. Background

Figure G.7.1 shows that 44% and 52 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively are 25 to 44 years old and 38 % and 30 % of them are 45 to 64 years old. Only 6 % and 4 % of visitors in Thecentre:mk and Lakeside Shopping Centre respectively are 65 years old or over. This composition might be due to two main reasons: most of the customers in shopping centres are 25 to 64 years old, probably being the most affluent age group, and the 25 to 64s are more available for being interviewed.

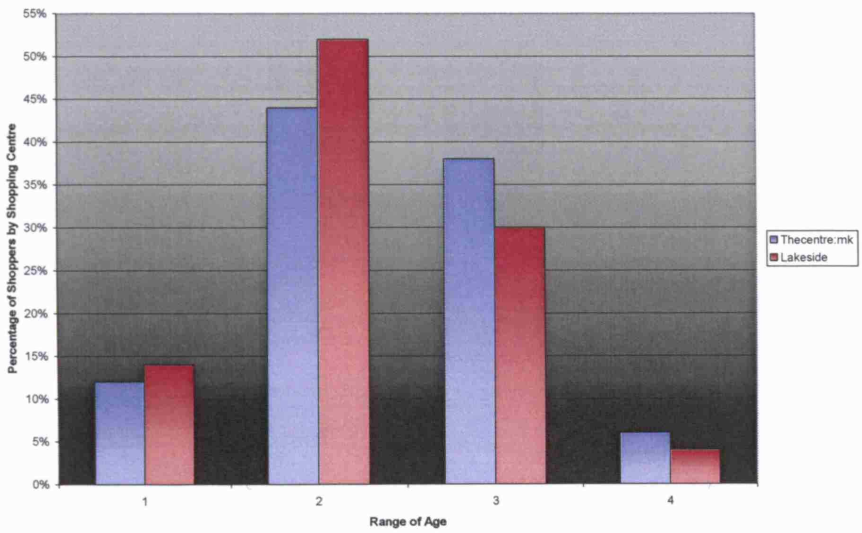

Figure G.7.1. Composition of shoppers by range of age.

(Scale: 1 = 18-24, 2 = 25-44, 3 = 45-64, 4 = 65 or over)

Figure G.7.2 shows that the composition of shoppers interviewed by gender is not considerably different in the two shopping centres. In fact, in Thecentre:mk 56 % of visitors are male and 44 % female; almost on the contrary, in Lakeside Shopping Centre 54 % of visitors are female and 46 % male. The difference in the composition of interviewees is so slight that does not affect the results of the statistical analysis.

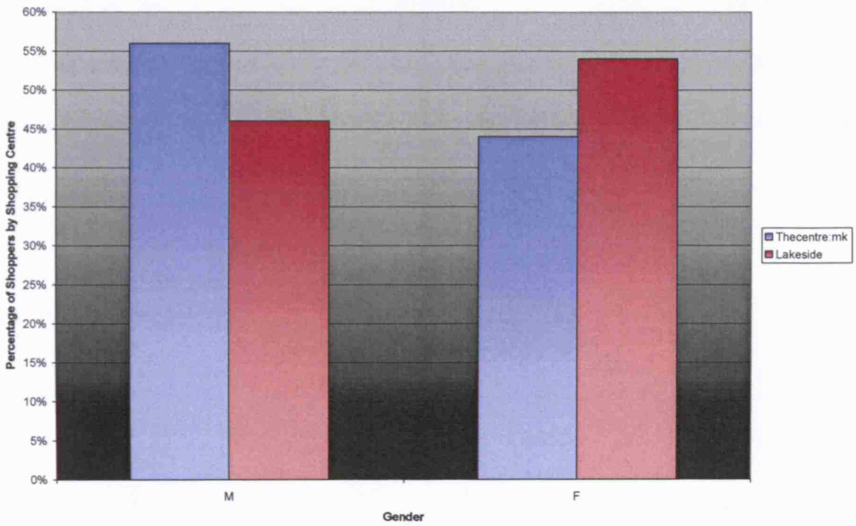

Figure G.7.2. Composition of shoppers by gender.

(Scale: M = Male, F = Female)

Figure G.7.3 shows that in both shopping centre 48 % of shoppers interviewed have been for 1 to 2 hours in the buildings at the time of the survey. This means that the answers of most people are reliable because at the moment of the interview they have already had enough time to get accustomed to and appraise the internal environmental conditions.

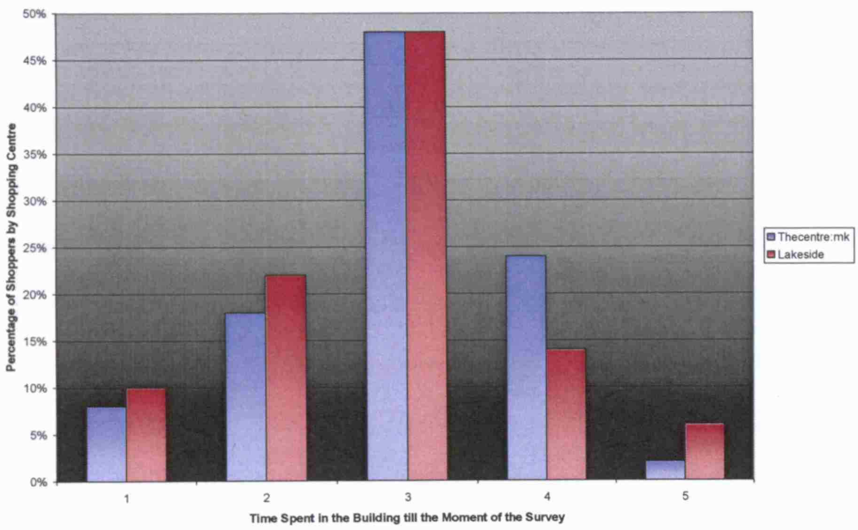

Figure G.7.3. Comparison of the time spent in the building till the moment of the survey.

(Scale: 1 = Less than 30 minutes, 2 = 30-60 minutes, 3 = 1-2 hours, 4 = 2-4 hours, 5 = 4-6 hours)

Figure G.7.4 shows that 54 % and 56 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively spend 2 to 4 hours in the buildings on a typical shopping trip. That is to say that most people spend half day at best in the shopping centres, considering a day made up of 8 working hours.

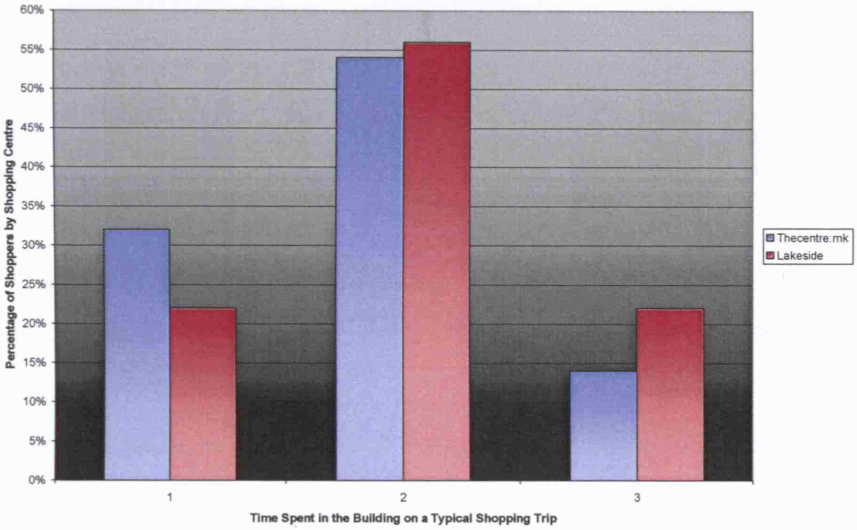

Figure G.7.4. Comparison of the time spent in the building on a typical shopping trip.

(Scale: 1 = 0-2 hours, 2 = 2-4 hours, 3 = 4-8 hours)

2. Thermal comfort

Figure G.7.5 shows that for 54 % and 50 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the predicted mean vote (PMV) is neutral. That is to say that most people consider satisfactory the temperature in the shopping centres. However, in Thecentre:mk for 28 % of visitors the internal conditions are slightly warm. The shifting from the neutrality is opposite in Lakeside Shopping Centre, where for 18 % of visitors the internal conditions are slightly cool. In both shopping centres, nobody consider them cold. In Thecentre:mk nobody rates the environment hot and in Lakeside Shopping Centre only 2 % of customers does. On the whole, the temperature is satisfactory in the common areas of both shopping centres but has an opposite trend, according to the PMV: increasing in Thecentre:mk and decreasing in Lakeside Shopping Centre.

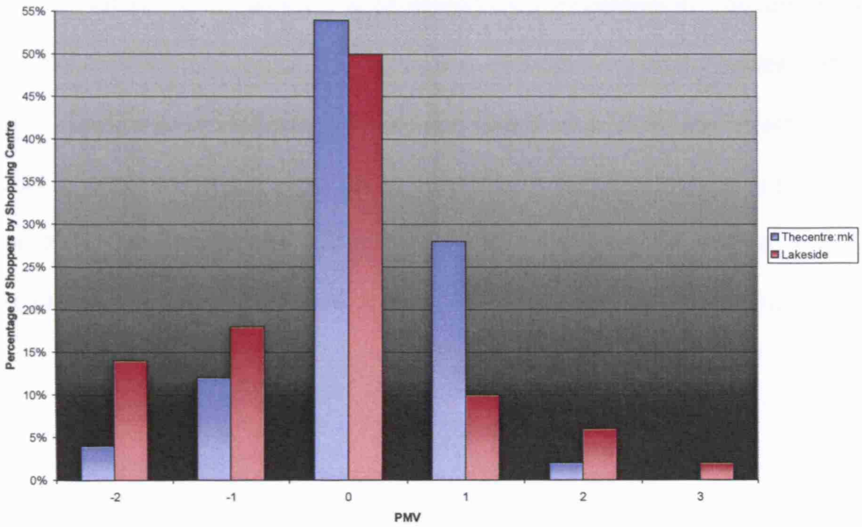

Figure G.7.5. Comparison of the PMV in the area surveyed at the time of the survey.

(Scale: -3 = Cold, -2 = Cool, -1 = Slightly cool, 0 = Neutral, 1 = Slightly warm, 2 = Warm, 3 = Hot)

Figure G.7.6 shows that for 64 % and 92 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the air movement is satisfactory. In both shopping centres nobody rates the air movement fairly draughty or too draughty. In Lakeside Shopping Centre nobody rates the air movement too still and in Thecentre:mk only 4 % of customers does. However, while in Lakeside Shopping Centre most people consider the air movement in the common areas satisfactory, in Thecentre:mk about two thirds of them (64 %) rate it satisfactory but one third (32 %) fairly still.

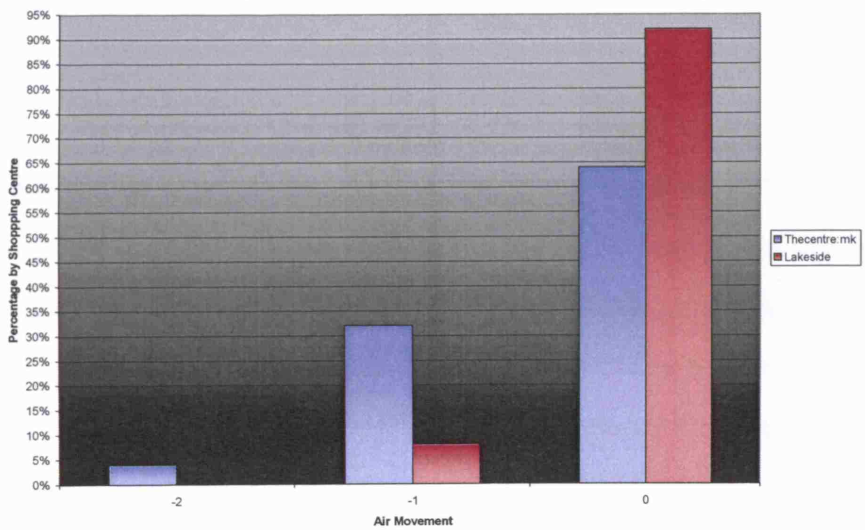

Figure G.7.6. Comparison of the air movement in the area surveyed at the time of the survey.

(Scale: -2 = Too still, -1 = Fairly still, 0 = Satisfactory, 1 = Fairly draughty, 2 = Too draughty)

Figure G.7.7 shows that for 60 % and 70 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the air quality is neutral. In both shopping centres nobody rates the air quality very stuffy. In Lakeside Shopping Centre nobody rates the air quality very fresh and in Thecentre:mk only 2 % of customers does. In addition, 30 % and 18 % of visitors in Thecentre:mk and Lakeside Shopping Centre respectively consider the air quality fresh. Therefore, in the common areas of both shopping centres the air quality is tendentially considered fresh, even though most people rate it satisfactory.

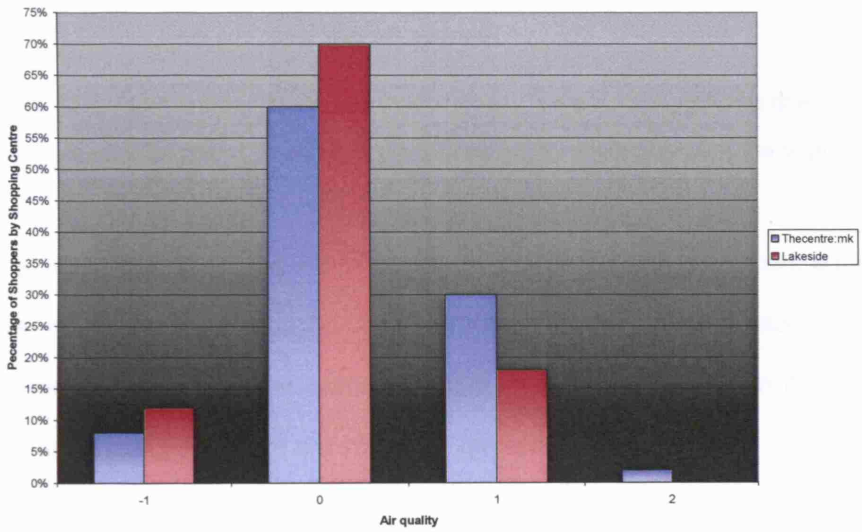

Figure G.7.7. Comparison air quality in the area surveyed at the time of the survey.

(Scale: -2 = Very stuffy, -1 = Stuffy, 0 = Neutral, 1 = Fresh, 2 = Very fresh)

3. Lighting

Figure G.7.8 shows that for about two thirds of shoppers interviewed (64 % and 58 % in Thecentre:mk and Lakeside Shopping Centre respectively) the quality of the natural lighting is satisfactory, while for about one third (36 % and 28 % in Thecentre:mk and Lakeside Shopping Centre respectively) it is fairly bright. In Thecentre:mk nobody rates the quality of the natural lighting too dim, fairly dim or too bright. Therefore, in the common areas of both shopping centres most people are satisfied with the natural lighting level.

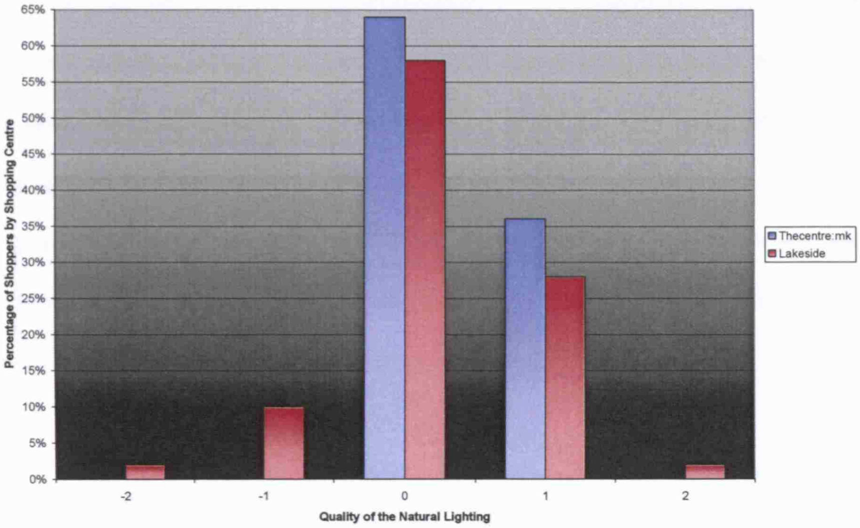

Figure G.7.8. Comparison of the quality of the natural lighting in the area surveyed at the time of the survey.

(Scale: -2 = Too dim, -1 = Fairly dim, 0 = Satisfactory, 1 = Fairly bright, 2 = Too bright)

Figure G.7.9 shows that for 86 % and 68 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the quality of the artificial lighting is satisfactory. In both shopping centres nobody rates the quality of the artificial lighting too dim. Therefore, in the common areas of both shopping centres most people are satisfied with the artificial lighting level.

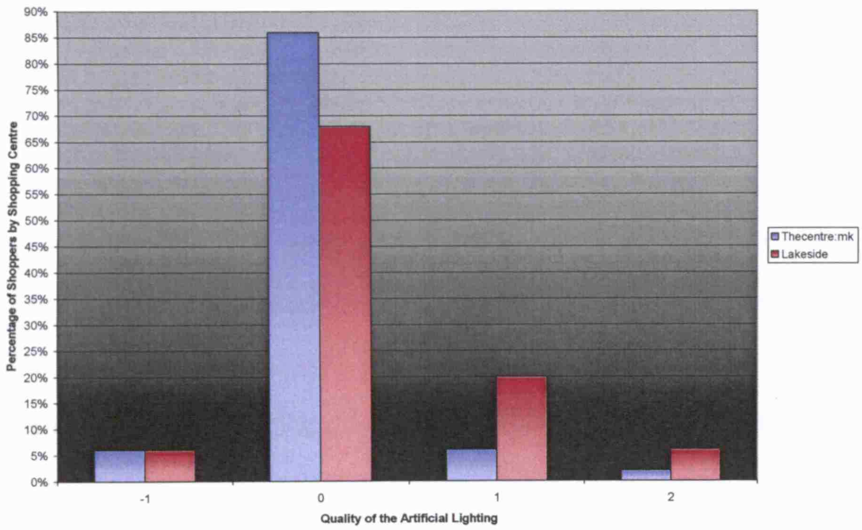

Figure G.7.9. Comparison of the quality of the artificial lighting in the area surveyed at the time of the survey.

(Scale: -2 = Too dim, -1 = Fairly dim, 0 = Satisfactory, 1 = Fairly bright, 2 = Too bright)

Figure G.7.10 shows that 56 % and 42 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively do not perceive glare or uncomfortable brightness from sun and sky. However, 24 % and 34 % of visitors in Thecentre:mk and Lakeside Shopping Centre respectively perceive glare or uncomfortable brightness from natural lighting occasionally. In Lakeside Shopping Centre nobody perceives it continuously and in Thecentre:mk only 2 % of customers does. On the whole, in the common areas of both shopping centres glare from sun and sky may cause discomfort to the shoppers, even though the control of it is generally satisfactory.

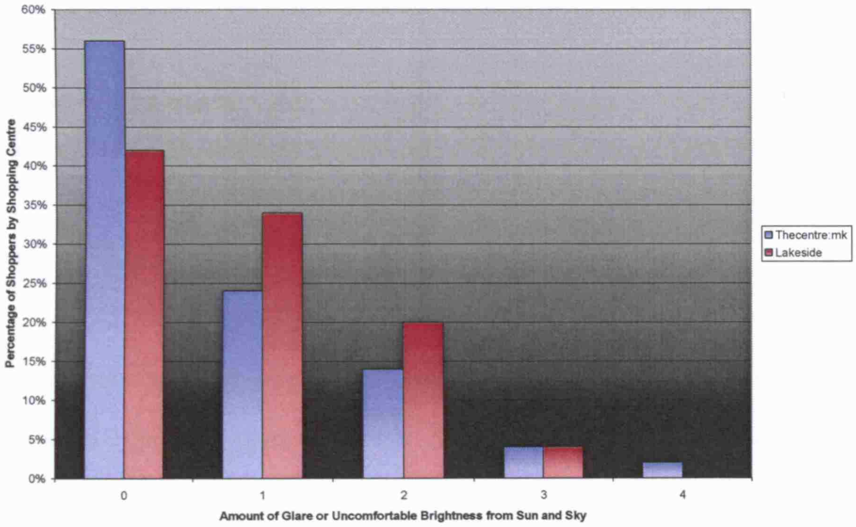

Figure G.7.10. Comparison of the amount of glare or uncomfortable brightness from sun and sky in the area surveyed at the time of the survey. (Scale: 0 = None, 1 = Occasional, 2 = Moderate, 3 = Considerable, 4 = Continuous)

Figure G.7.11 shows that 74 % and 54 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively do not perceive glare or uncomfortable brightness from lights. In both shopping centres nobody perceives it continuously. In the Thecentre:mk nobody rates it considerable and in Lakeside Shopping Centre only 4 % of customers does. On the whole, in the common areas of both shopping centres glare from lights may cause discomfort to the shoppers, even though the control of it is generally satisfactory.

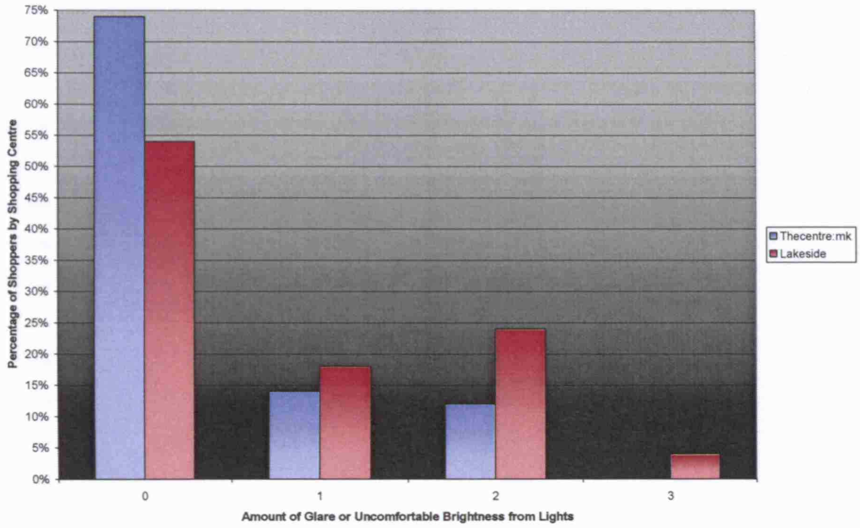

Figure G.7.11. Comparison of the amount of glare or uncomfortable brightness from lights in the area surveyed at the time of the survey. (Scale: 0 = None, 1 = Occasional, 2 = Moderate, 3 = Considerable, 4 = Continuous)

4. Overall comfort

Figure G.7.12 shows that for 38 % and 52 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the overall comfort of the common areas is satisfactory, while for 58 % and 46 % of them it is good. However, only 4 % and 2 % of visitors consider it very good. In both shopping centres nobody rates the overall comfort of the common areas bad or very bad. On the whole, the common areas of the buildings are considered comfortable, even though the answers of the interviewees suggest that the environmental conditions of these areas may be still improved.

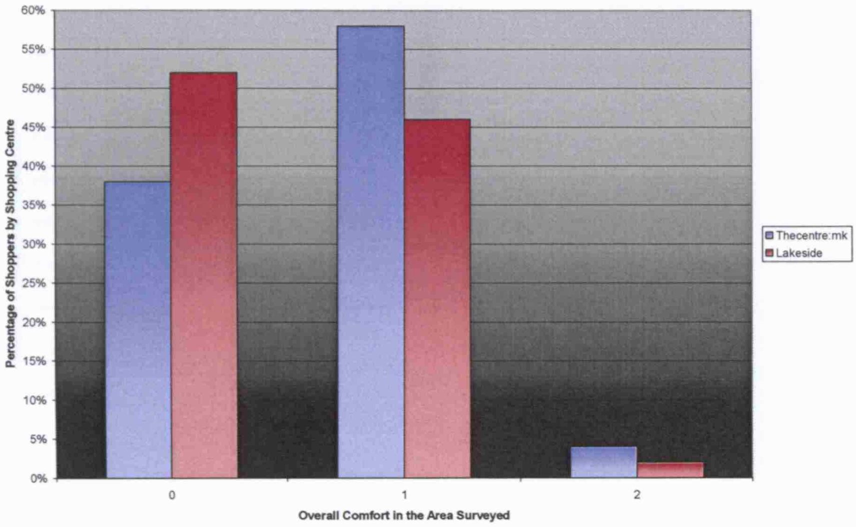

Figure G.7.12. Comparison of the overall comfort in the area surveyed at the time of the survey.

(Scale: -2 = Very bad, -1 = Bad, 0 = Satisfactory, 1 = Good, 2 = Very good)

Figure G.7.13 shows that for 34 % and 46 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the overall comfort of the whole building is satisfactory, while for 54 % and 42 % of them it is good. However, 10 % and 12 % of visitors consider the overall comfort very good. In both shopping centres nobody rates the overall comfort of the whole building very bad. In Lakeside Shopping Centre nobody rates the overall comfort bad, while in Thecentre:mk 2 % of customers does. Therefore, the whole buildings are considered comfortable, even though the answers of the interviewees suggest that the environmental conditions of these shopping centres may be still improved.

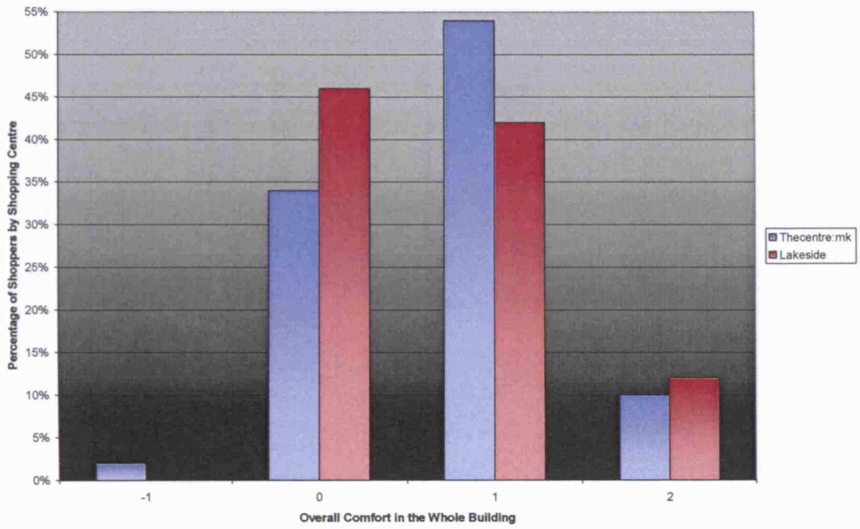

Figure G.7.13. Comparison of the overall comfort in the whole building in general.

(Scale: -2 = Very bad, -1 = Bad, 0 = Satisfactory, 1 = Good, 2 = Very good)

5. Improvement

Figure G.7.14 shows that for 11 % and 16 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively, the common areas of the buildings do not need any improvement. In Thecentre:mk the items that need to be most and least improved upon are the air movement (for 33 % of visitors) and the natural lighting (for 5 % of visitors) respectively, while in Lakeside Shopping Centre they are the natural lighting (for 24 % of visitors) and the artificial lighting (for 4 % of visitors) respectively. In Thecentre:mk temperature and air quality are also considered to be improved upon for 19 % and 18 % of customers respectively. In Lakeside Shopping Centre both temperature and air movement need improvements for 22 % of customers too. On the whole, in both shopping centres the aspects related to the thermal comfort of the common areas need more improvements, but in Lakeside Shopping Centre natural lighting needs also special attention.

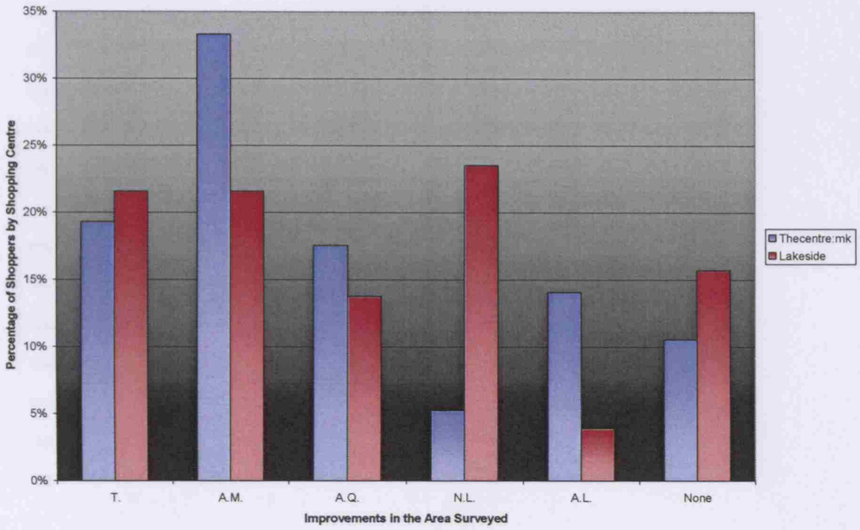

Figure G.7.14. Comparison of the improvements suggested by the shoppers in the area surveyed.

(Scale: T. = Temperature, A.M. = Air movement, A.Q. = Air quality, N.L. = Natural lighting, A.L. = Artificial lighting)

6. Shopping conditions

Figure G.7.15 shows that 56 % and 42 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively will probably stay for 3 to 4 hours in the buildings. That is to say that most people will spend almost half day in the shopping centres, considering a day made up of 8 working hours. This answer confirms the result of Figure G.7.4, according to which visitors usually spend 2 to 4 hours in the shopping centres on a typical shopping trip. In Thecentre:mk nobody will be for 7 to 8 hours in the building, that is to say for the whole day, and in Lakeside Shopping Centre only 2 % will do. However, many customers (28 % and 32 % in Thecentre:mk and Lakeside Shopping Centre respectively) will stay for 1 to 2 hours in the buildings.

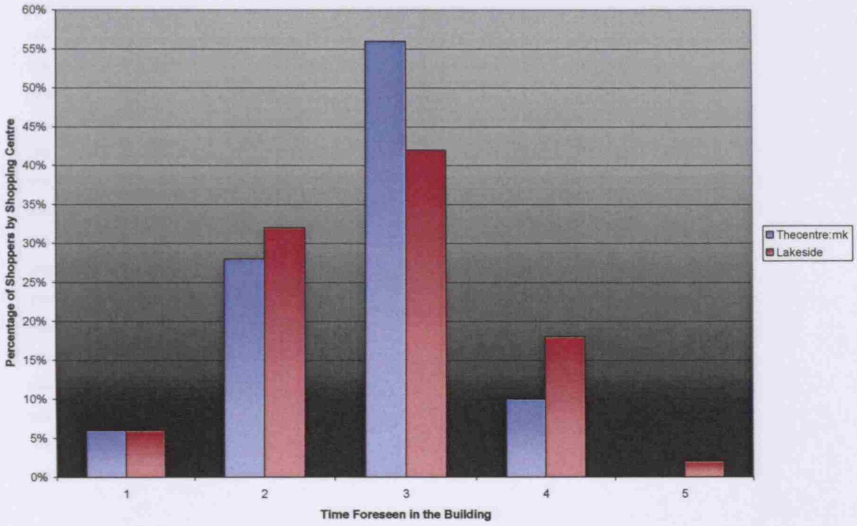

Figure G.7.15. Comparison of the total time the shoppers will spend in the building on the day of the survey.

(Scale: 1 = Less than 1 hour, 2 = 1-2 hours, 3 = 3-4 hours, 4 = 5-6 hours, 5 = 7-8 hours)

Figure G.7.16 shows that 66 % and 76 % of shoppers interviewed in Thecentre:mk and Lakeside Shopping Centre respectively would not stay longer in the buildings, if the environmental conditions were perfect. This means that more than two thirds of the interviewees do not consider the environmental conditions a priority in their decision of having a shopping trip. However, this does not mean that the environmental conditions may not affect the customer's choice of a shopping centre instead of another and the survey reveals that shoppers are quite critical toward the internal conditions. In Thecentre:mk nobody would stay for 7 to 8 hours longer in the building, that is to say for the whole working day, and in Lakeside Shopping Centre only 2 % would do.

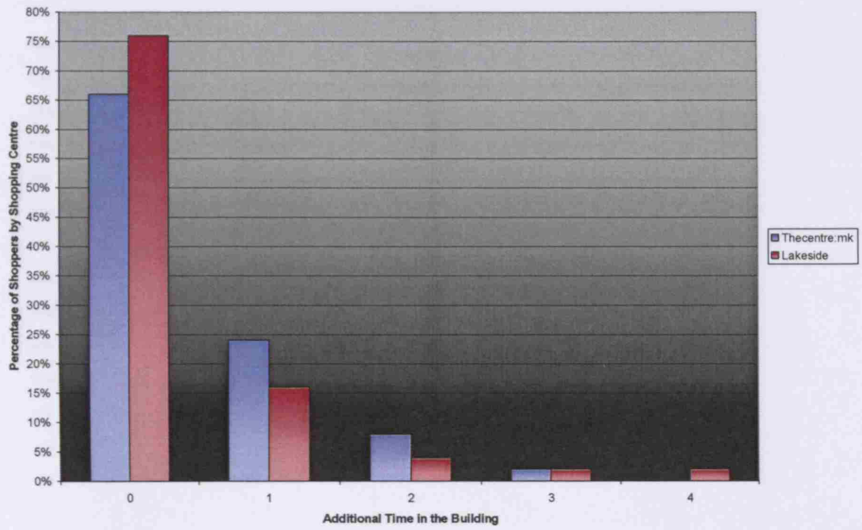

Figure G.7.16. Comparison of the additional time the shoppers would spend in the building if the environmental conditions were perfect. (Scale: 0 = 0 hours, 1 = 1-2 hours, 2 = 3-4 hours, 3 = 5-6 hours, 4 = 7-8 hours)

Appendix G.8. Analysis of the responses of tenants

1. Background

Figure G.8.1 shows that 59 % and 68 % of shop assistants interviewed in Thecentre:mk and Lakeside Shopping Centre respectively are 18 to 24 years old and 35 % and 26 % of them are 25 to 44 years old. Only 6 % and 5 % of shop assistants in Thecentre:mk and Lakeside Shopping Centre respectively are 45 to 64 years old. This composition might be due to two main reasons: most of the people working in shops are 18 to 24 years old and the 18 to 24s are more available for being interviewed.

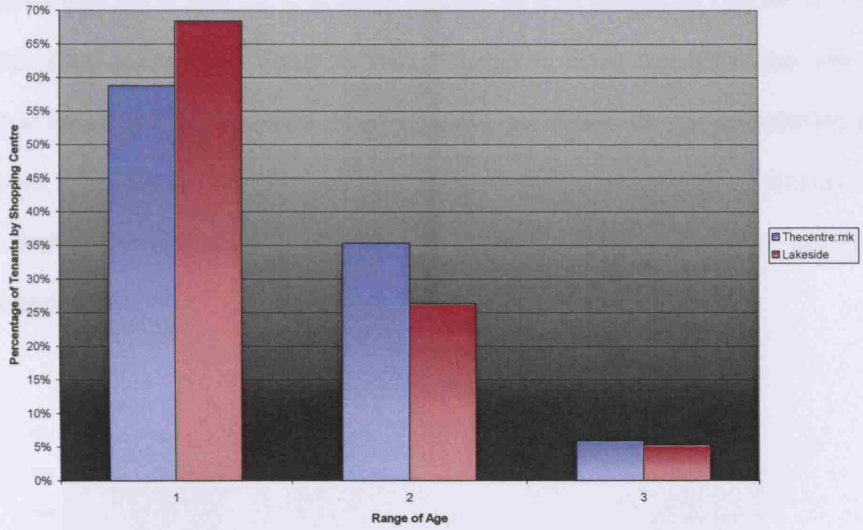

Figure G.8.1. Composition of tenants by range of age.

(Scale: 1 = 18-24, 2 = 25-44, 3 = 45-64, 4 = 65 or over)

Figure G.8.2 shows that the composition of shop assistants interviewed by gender is considerably different in the Thecentre:mk, where 26 % of people working in the shops are male and 74 % female. Instead, in Lakeside Shopping Centre the composition of shop assistants interviewed by gender is completely balanced as 50 % of people working in the shops are male and 50 % female. In Thecentre:mk the difference in the composition of interviewees is so considerable that might affect the results of the statistical analysis of this shopping centre.

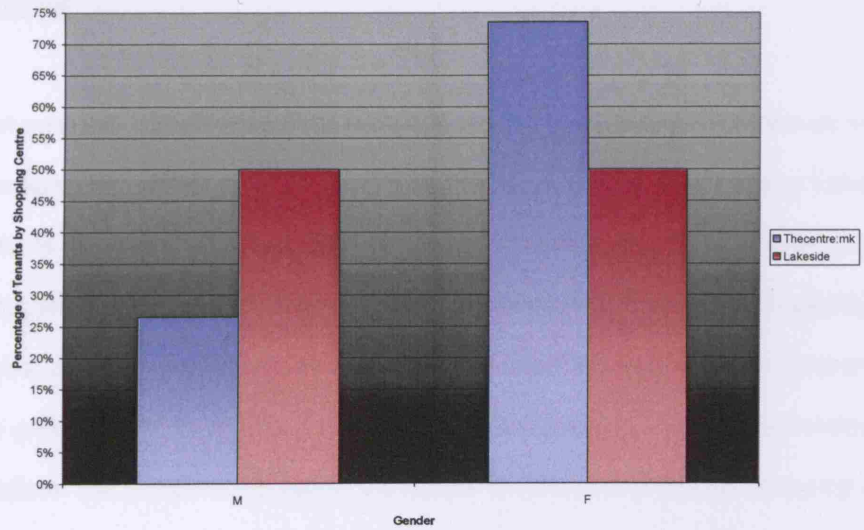

Figure G.8.2. Composition of tenants by gender.

(Scale: M = Male, F = Female)

Figure G.8.3 shows that 56 % and 45 % of shop assistants interviewed in Thecentre:mk and Lakeside Shopping Centre respectively have been for 4 to 6 hours in the buildings at the time of the survey. That is to say that most people have spent half day at least in the shops, considering a day made up of 8 working hours. This means that the answers of most people are reliable because at the moment of the interview they have already had enough time to get accustomed to and appraise the internal environmental conditions.

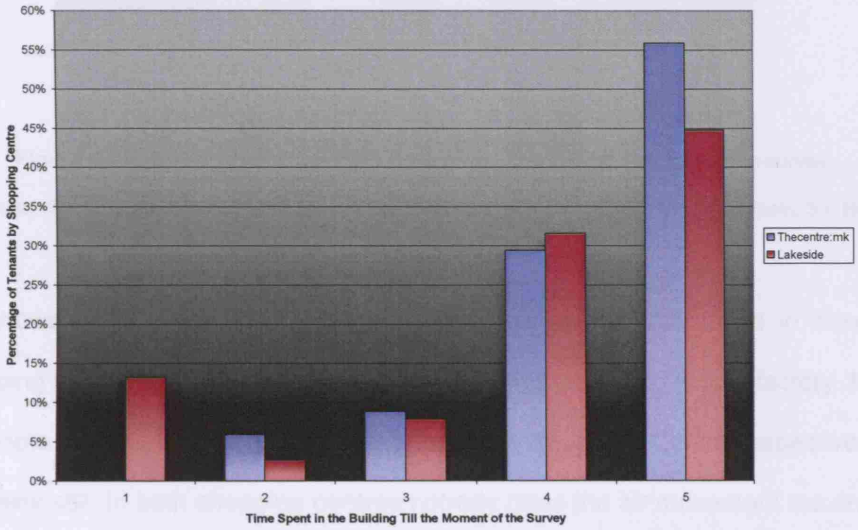

Figure G.8.3. Comparison of the time spent in the building till the moment of the survey.

(Scale: 1 = Less than 30 minutes, 2 = 30-60 minutes, 3 = 1-2 hours, 4 = 2-4 hours, 5 = 4-6 hours)

2. Thermal comfort

Figure G.8.4 shows that for almost one third (29 %) of shop assistants interviewed in Thecentre:mk the predicted mean vote (PMV) is slightly cool, while for the same percentage in Lakeside Shopping Centre the PMV is neutral. On the opposite for 26 % of people working in Thecentre:mk the PMV is neutral, while for the same percentage in Lakeside Shopping Centre the PMV is slightly warm. In both shopping centres, nobody consider the internal conditions of the shops hot. In Thecentre:mk nobody rates the shop environment cold and in Lakeside Shopping Centre only 3 % of shopping assistants does. On the whole, the temperature inside the shops is satisfactory in both shopping centres but the PMV tends to shift easily from the condition of neutrality. This might due to the fact that each shop controls its own HVAC system.

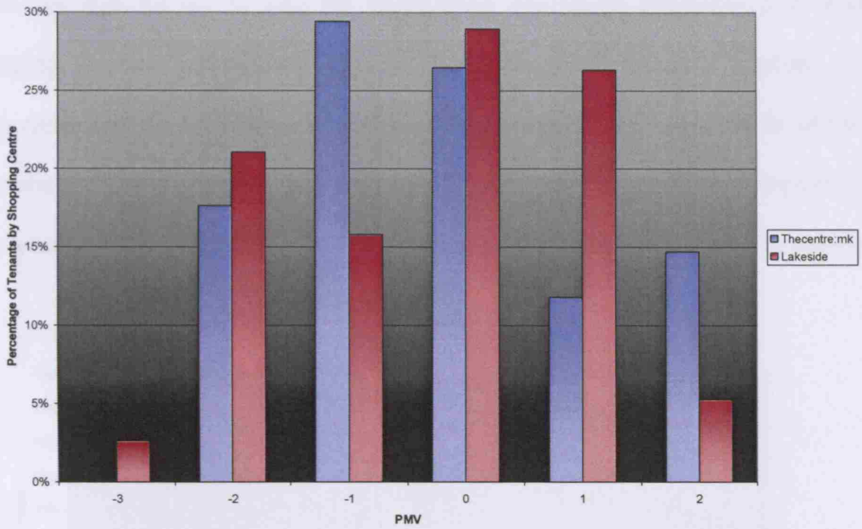

Figure G.8.4. Comparison of the PMV in the shops surveyed at the time of the survey.

(Scale: -3 = Cold, -2 = Cool, -1 = Slightly cool, 0 = Neutral, 1 = Slightly warm, 2 = Warm, 3 = Hot)

Figure G.8.5 shows that for 65 % and 55 % of shop assistants interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the air movement in their shops is satisfactory. However, 24 % and 29 % of people working in Thecentre:mk and Lakeside Shopping Centre respectively consider the air movement fairly still. In both shopping centres nobody rates the air movement too draughty. On the whole, in both shopping centres the air movement inside the shops is satisfactory but tendentially fairly still.

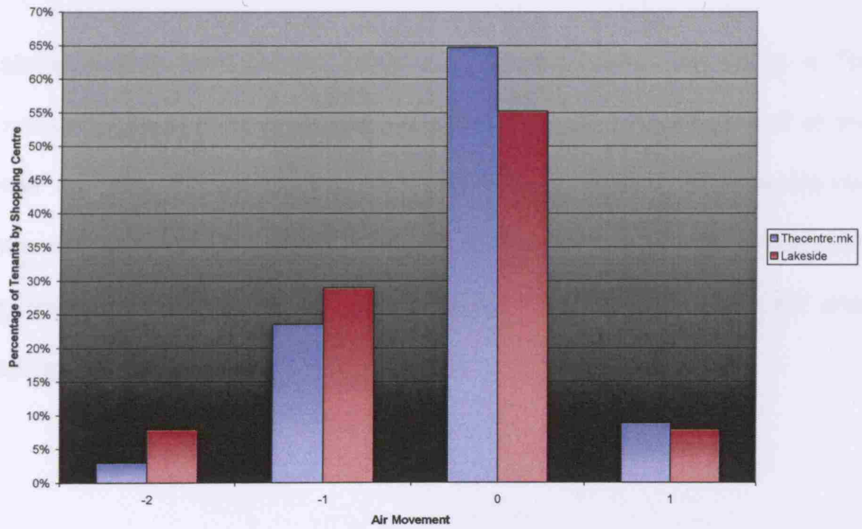

Figure G.8.5. Comparison of the air movement in the shops surveyed at the time of the survey.

(Scale: -2 = Too still, -1 = Fairly still, 0 = Satisfactory, 1 = Fairly draughty, 2 = Too draughty)

Figure G.8.6 shows that for 53 % and 68 % of shop assistants interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the air quality in their shops is neutral. In both shopping centres nobody rates the air quality very stuffy or very fresh. In addition, 18 % of people working in Thecentre:mk consider the air quality stuffy, while 32 % of them in Lakeside Shopping Centre consider it fresh. On the whole, in both shopping centres the air quality inside the shops is satisfactory.

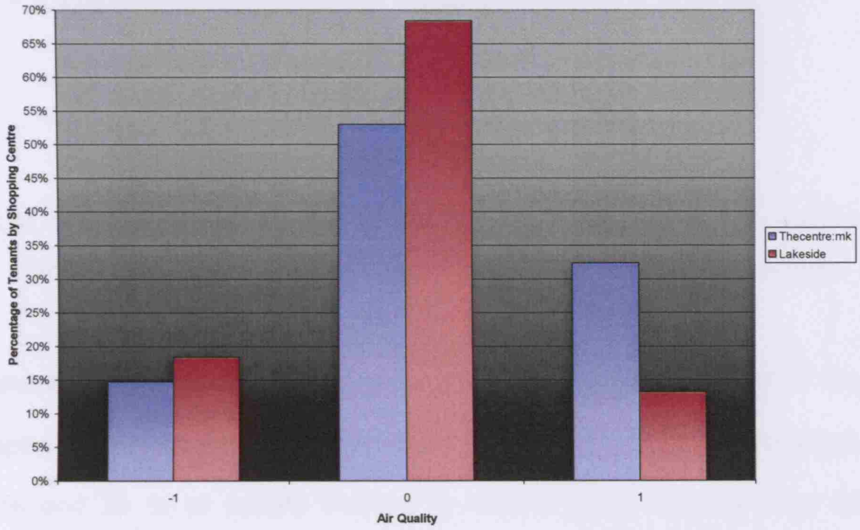

Figure G.8.6. Comparison of the air quality in the shops surveyed at the time of the survey.

(Scale: -2 = Very stuffy, -1 = Stuffy, 0 = Neutral, 1 = Fresh, 2 = Very fresh)

3. Lighting

Figure G.8.7 shows that for almost two thirds of shop assistants interviewed in Thecentre:mk the quality of the natural lighting in their shops is satisfactory, while for about half of them in Lakeside Shopping Centre too dim. Only 6 % and 5 % of people working in Thecentre:mk and Lakeside Shopping Centre respectively consider the natural lighting too bright. Therefore, with regard to the natural lighting level in the shops most people are satisfied in Thecentre:mk and unsatisfied in Lakeside Shopping Centre.

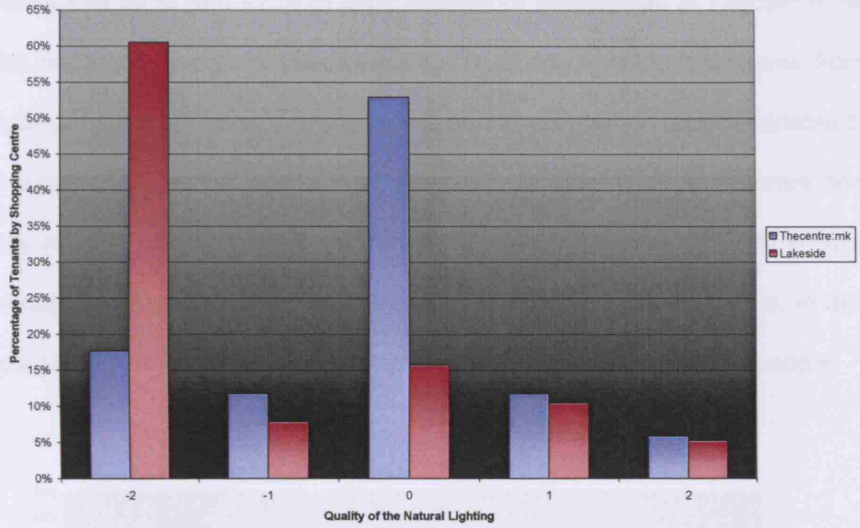

Figure G.8.7. Comparison of the quality of the natural lighting in the shops surveyed at the time of the survey.

(Scale: -2 = Too dim, -1 = Fairly dim, 0 = Satisfactory, 1 = Fairly bright, 2 = Too bright)

Figure G.8.8 shows that for 65 % and 47 % of shop assistants interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the quality of the artificial lighting in their shops is satisfactory. However, 24 % and 29 % of people working in Thecentre:mk and Lakeside Shopping Centre respectively consider the artificial lighting fairly bright. In both shopping centres only 3 % of people rates the artificial lighting too dim and another 3 % in Thecentre:mk fairly dim. Therefore, in the shops of both shopping centres most people are satisfied with the artificial lighting level.

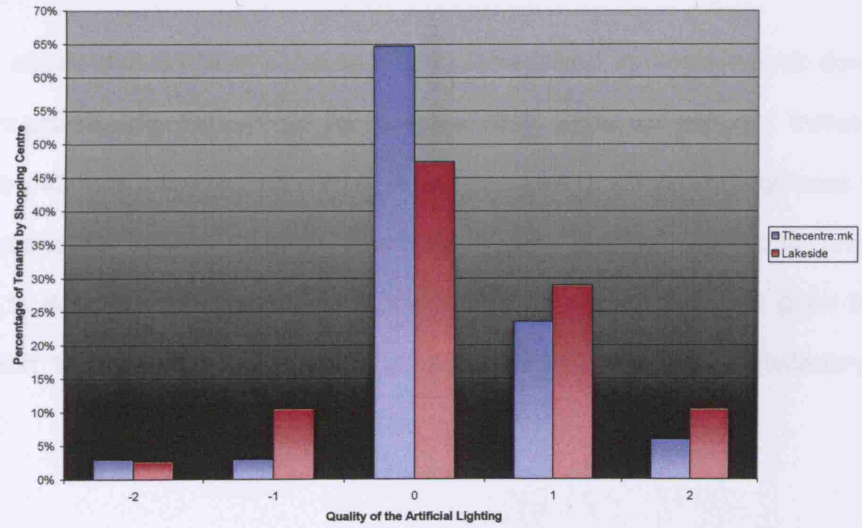

Figure G.8.8. Comparison of the quality of the artificial lighting in the shops surveyed at the time of the survey.

(Scale: -2 = Too dim, -1 = Fairly dim, 0 = Satisfactory, 1 = Fairly bright, 2 = Too bright)

Figure G.8.9 shows that 59 % and 92 % of shop assistants interviewed in Thecentre:mk and Lakeside Shopping Centre respectively do not perceive glare or uncomfortable brightness from sun and sky. However, 24 % of people working in Thecentre:mk perceives glare or uncomfortable brightness from natural lighting occasionally, while only 3 % of them in Lakeside Shopping Centre does. In Lakeside Shopping Centre nobody perceives it considerably and in Thecentre:mk only 6 % of interviewees does. In both shopping centres nobody perceives it continuously. On the whole, in the shops of both shopping centres glare from sun and sky usually does not cause discomfort to people.

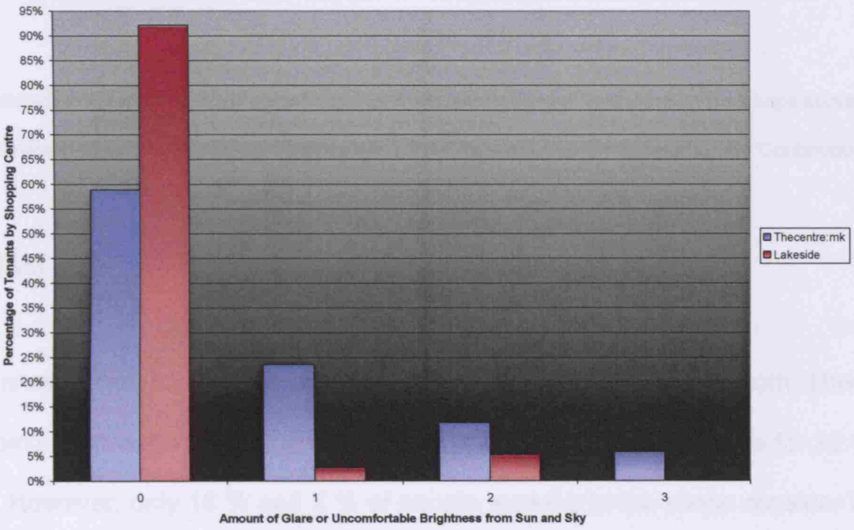

Figure G.8.9. Comparison of the amount of glare or uncomfortable brightness from sun and sky in the shops surveyed at the time of the survey. (Scale: 0 = None, 1 = Occasional, 2 = Moderate, 3 = Considerable, 4 = Continuous)

Figure G.8.10 shows that 50 % of shop assistants interviewed in Thecentre:mk does not perceive glare or uncomfortable brightness from lights, while 26 % does occasionally. Instead, in Lakeside Shopping Centre 42 % of people does not perceive glare or uncomfortable brightness from lights and 42 % does occasionally. In Thecentre:mk nobody perceives it continuously and in Lakeside Shopping Centre only 3 % does. On the whole, in the shops of both shopping centres glare from lights may cause discomfort to people, even though the control of it is generally satisfactory especially in Thecentre:mk.

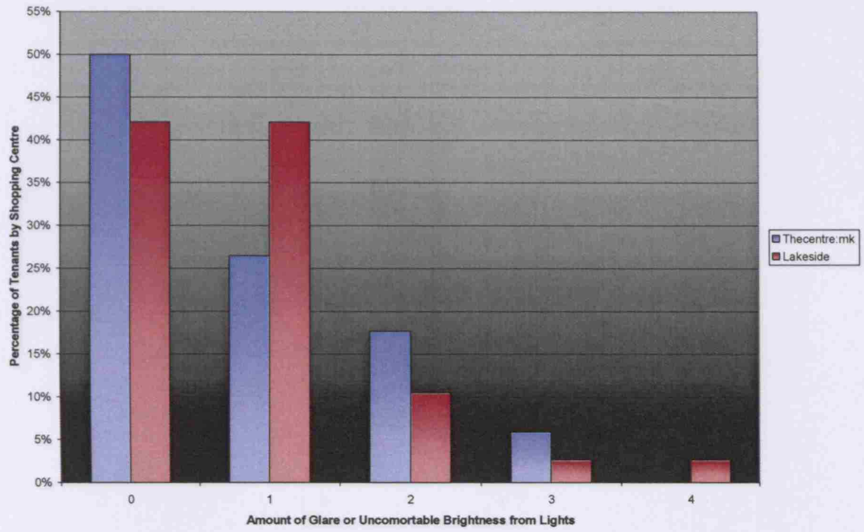

Figure G.8.10. Comparison of the amount of glare or uncomfortable brightness from lights in the shops surveyed at the time of the survey. (Scale: 0 = None, 1 = Occasional, 2 = Moderate, 3 = Considerable, 4 = Continuous)

4. Overall comfort

Figure G.8.11 shows that for half of the shop assistants interviewed in both Thecentre:mk and Lakeside Shopping Centre the overall comfort of the shops is satisfactory, while for 32 % and 39 % of them it is good. However, only 18 % and 5 % of people working in the shops consider it very good. In both shopping centres nobody rates the overall comfort of the shops very bad. In Thecentre:mk nobody rates it bad, but in Lakeside Shopping Centre 5 % of people does. On the whole, the shops of the buildings are considered comfortable, even though the answers of the interviewees suggest that the environmental conditions of these shops may be still improved.

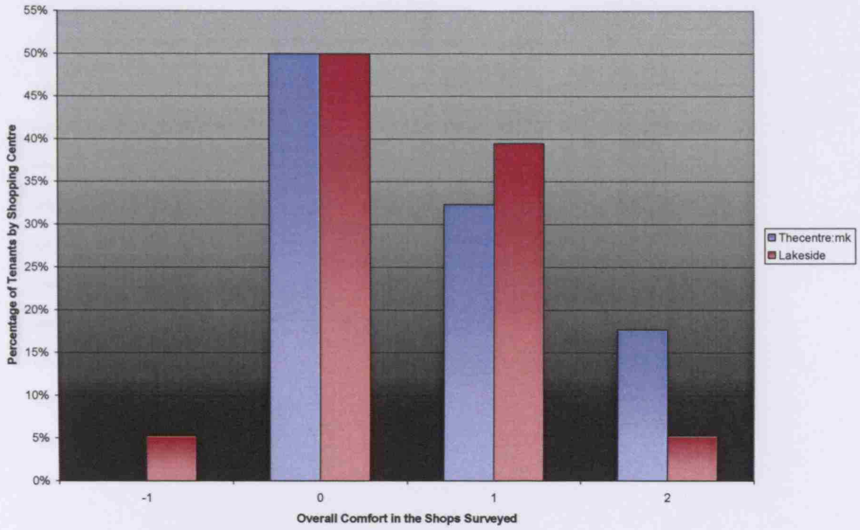

Figure G.8.11. Comparison of the overall comfort in the shops surveyed at the time of the survey.

(Scale: -2 = Very bad, -1 = Bad, 0 = Satisfactory, 1 = Good, 2 = Very good)

Figure G.8.12 shows that for 59 % and 42 % of shop assistants interviewed in Thecentre:mk and Lakeside Shopping Centre respectively the overall comfort of the whole building is satisfactory, while for 26 % and 50 % of them it is good. However, in Lakeside Shopping Centre nobody rates it very good, but in Thecentre:mk 6 % of people does. In both shopping centres nobody rates the overall comfort of the whole building very bad. Therefore, the whole buildings are considered comfortable, even though the answers of the interviewees suggest that the environmental conditions of these shopping centres may be still improved.

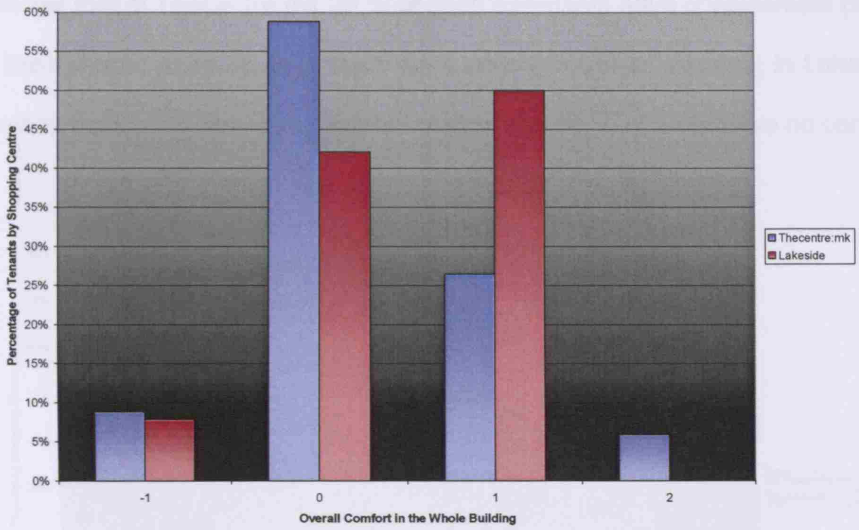

Figure G.8.12. Comparison of the overall comfort in the whole building in general.

(Scale: -2 = Very bad, -1 = Bad, 0 = Satisfactory, 1 = Good, 2 = Very good)

5. Personal control

Figure G.8.13 shows that in Thecentre:mk 26 % of shop assistants have considerable personal control over heating in their shops, while 21 % of them have full control and 21 % of them have no control at all. Instead, in Lakeside Shopping Centre 45 % of shop assistants have full personal control and 34 % of them have no control at all.

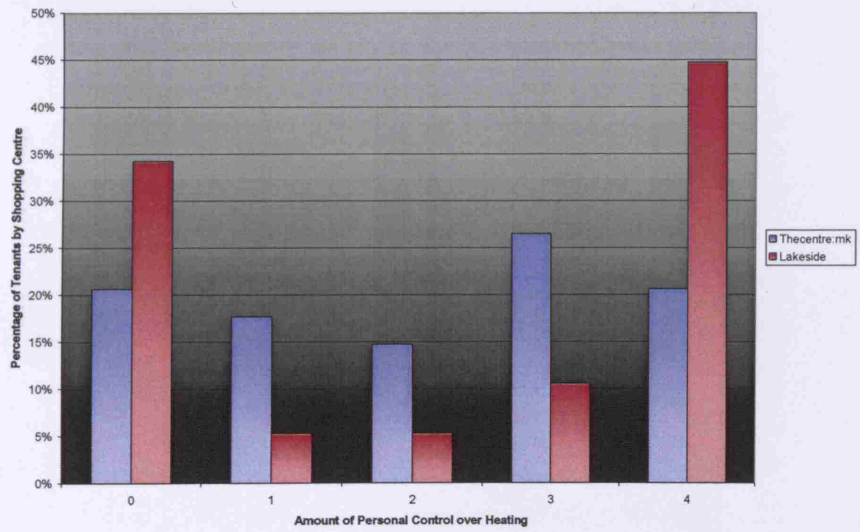

Figure G.8.13. Comparison of the amount of personal control the tenants have over heating in their shops.

(Scale: 0 = None, 1 = Limited, 2 = Moderate, 3 = Considerable, 4 = Full)

Figure G.8.14 shows that in Thecentre:mk 26 % of shop assistants have considerable personal control over cooling in their shops, while 26 % of them have no control at all. Instead, in Lakeside Shopping Centre 45 % of shop assistants have full personal control and 34 % of them have no control at all.

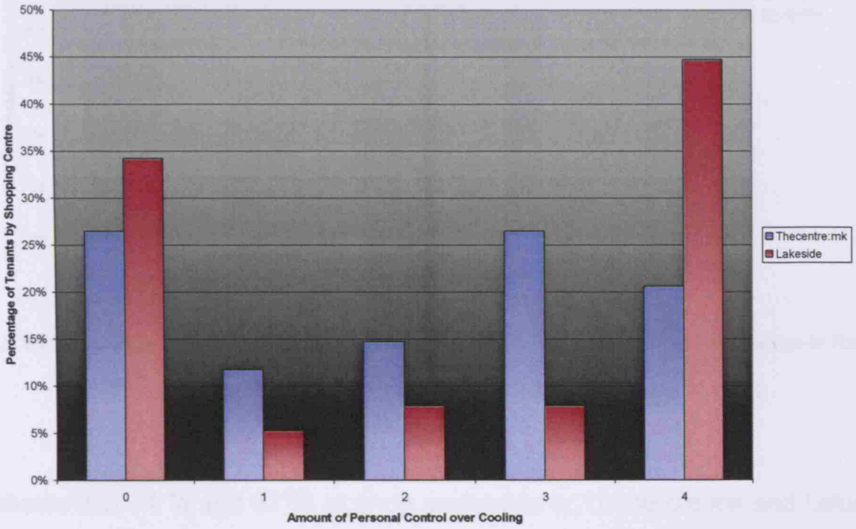

Figure G.8.14. Comparison of the amount of personal control the tenants have over cooling in their shops.

(Scale: 0 = None, 1 = Limited, 2 = Moderate, 3 = Considerable, 4 = Full)

Figure G.8.15 shows that 38 % and 42 % of shop assistants in Thecentre:mk and Lakeside Shopping Centre respectively have no personal control over ventilation in their shops, while 18 % and 37 % of them have full control.

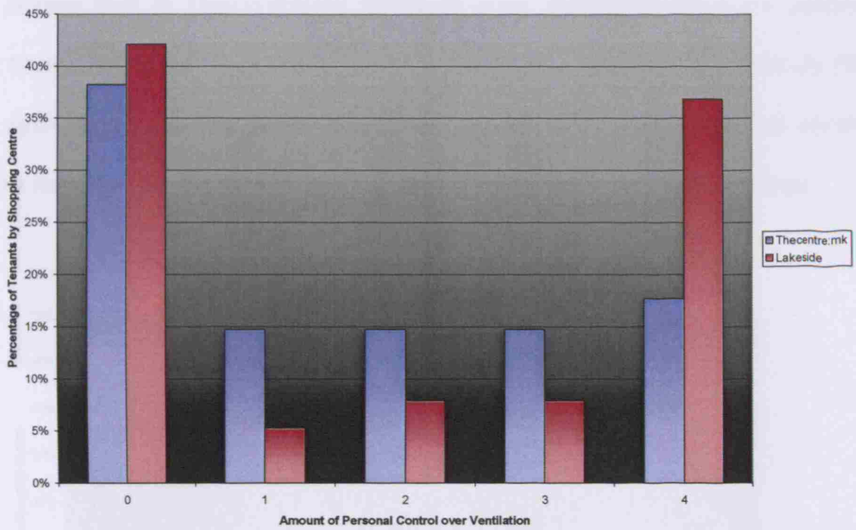

Figure G.8.15. Comparison of the amount of personal control the tenants have over ventilation in their shops.

(Scale: 0 = None, 1 = Limited, 2 = Moderate, 3 = Considerable, 4 = Full)

Figure G.8.16 shows that 74 % and 87 % of shop assistants in Thecentre:mk and Lakeside Shopping Centre respectively have no personal control over natural lighting in their shops. In both shopping centres nobody has considerable control. In Thecentre:mk nobody has full control, while in Lakeside Shopping Centre 8 % has.

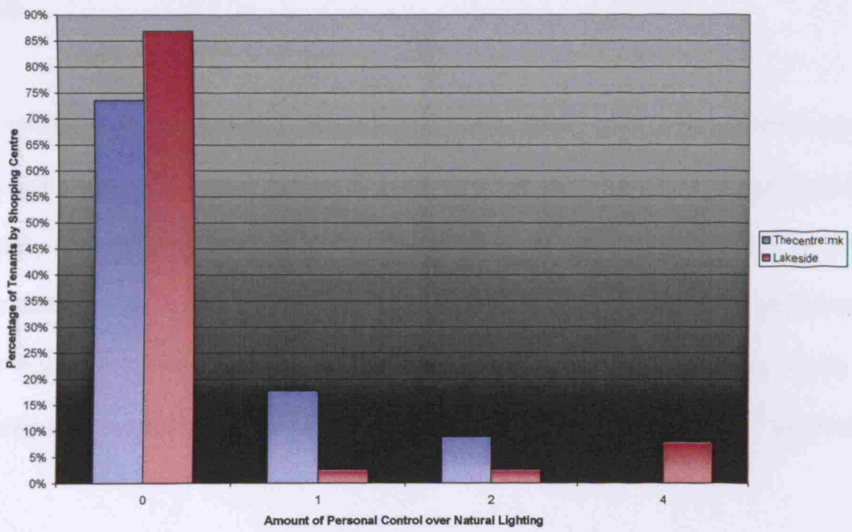

Figure G.8.16. Comparison of the amount of personal control the tenants have over natural lighting in their shops.

(Scale: 0 = None, 1 = Limited, 2 = Moderate, 3 = Considerable, 4 = Full)

Figure G.8.17 shows that in Thecentre:mk 35 % of shop assistants have no control over artificial lighting in their shops, while 24 % of them have limited control. Instead, in Lakeside Shopping Centre 47 % of shop assistants have no personal control and 39 % of them have full control. In Lakeside Shopping Centre nobody has moderate control, while in Thecentre:mk only 9 % has.

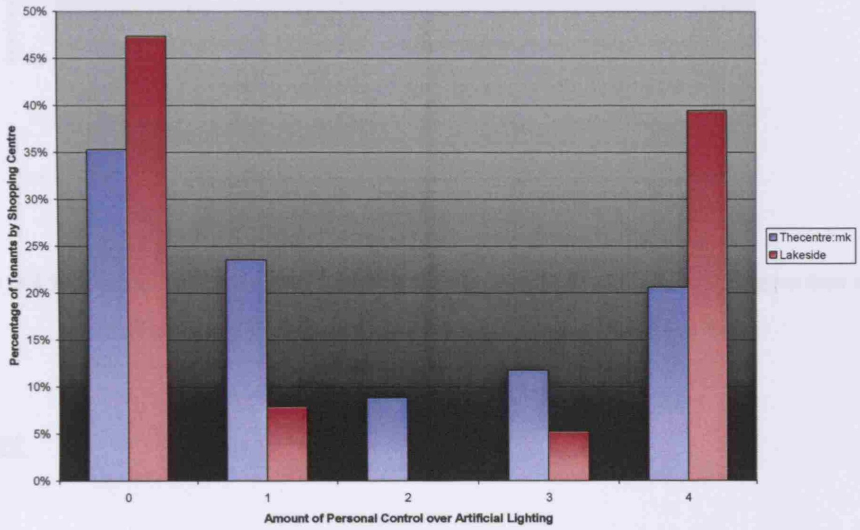

Figure G.8.17. Comparison of the amount of personal control the tenants have over artificial lighting in their shops. (Scale: 0 = None, 1 = Limited, 2 = Moderate, 3 = Considerable, 4 = Full)

6. Energy issue

Figure G.8.18 shows that in Lakeside Shopping Centre about one third of shop assistants (39 %) interviewed is not concerned at all about saving energy in their shops and about another one third (34 %) of them slightly. Instead, in Thecentre:mk 26 % of shop assistants interviewed is slightly concerned about it and another 26 % moderately. The complete indifference of shop assistants to the energy issue might be due to their non-involvement in the management of the shops, while an increase in their interest might be consequent to a campaign of sensitization promoted by their managers or tenants.

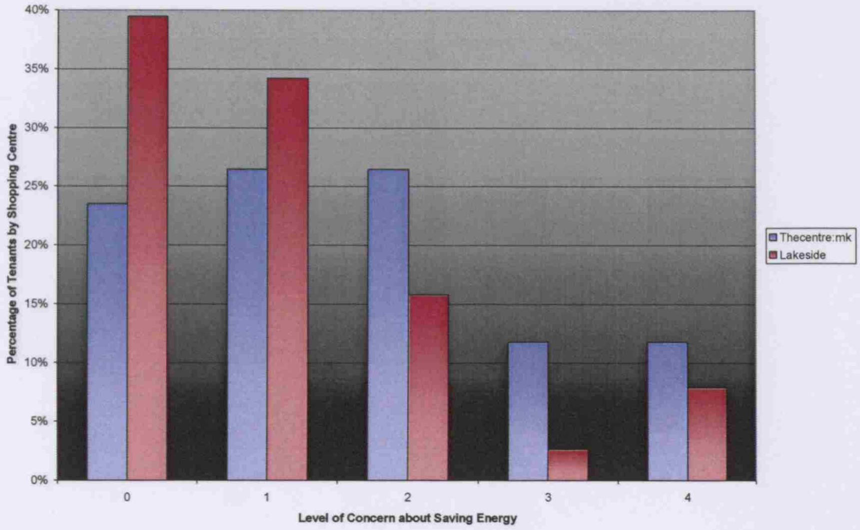

Figure G.8.18. Comparison of the level of concern the tenants have about saving energy in their shops.

(Scale: 0 = Not at all, 1 = Slightly, 2 = Moderately, 3 = Very, 4 = Fully)

7. <u>Improvement</u>

Figure G.8.19 shows that for only 3 % and 2 % of shop assistants interviewed in Thecentre:mk and Lakeside Shopping Centre respectively their shops do not need any improvement. For most people (33 % and 36 % in Thecentre:mk and Lakeside Shopping Centre respectively) the temperature needs to be most improved upon. The other items that also need improvements are the air quality for 30 % of people in Lakeside Shopping Centre and the natural lighting for 23 % in Thecentre:mk. On the whole, in both shopping centres the temperature in the shops, as main aspect related to the thermal comfort, needs more improvements, but the air quality in Lakeside Shopping Centre and the natural lighting in Thecentre:mk have to be considered among the most important improvements.

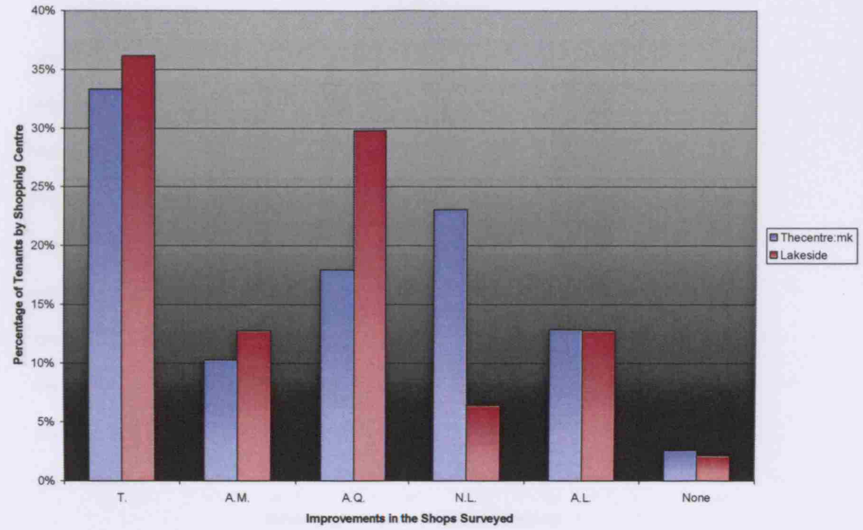

Figure G.8.19. Comparison of the improvements suggested by the tenants in their shops.

(Scale: T. = Temperature, A.M. = Air movement, A.Q. = Air quality, N.L. = Natural lighting, A.L. = Artificial lighting)

8. <u>Shopping and working conditions</u>

Figure G.8.20 shows that 47 % of shop assistants interviewed in both Thecentre:mk and Lakeside Shopping Centre consider the environmental conditions of their shops good for shopping. However, for 41 % and 39 % of the people working in Thecentre:mk and Lakeside Shopping Centre respectively they are just satisfactory. In Thecentre:mk nobody rates the environmental conditions of the shops very bad but in Lakeside Shopping Centre 3 % of interviewees does.

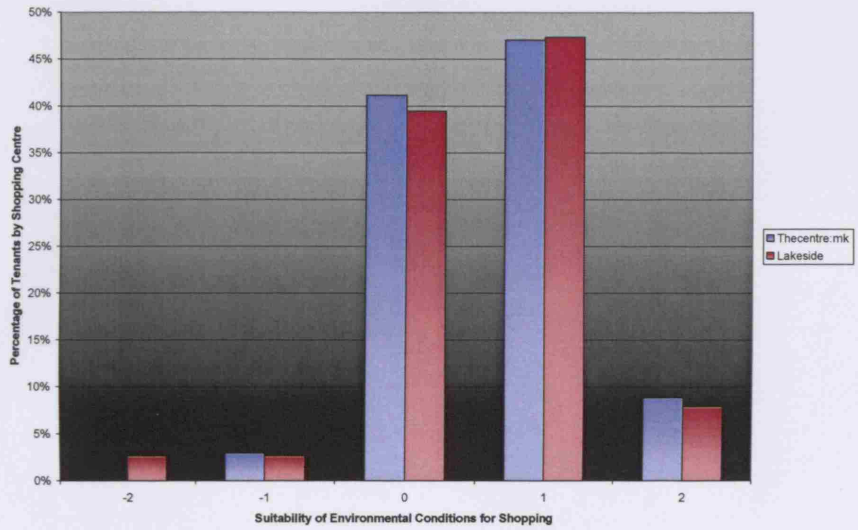

Figure G.8.20. Comparison of the suitability of the environmental conditions for shopping in the shops surveyed.

(Scale: -2 = Very bad, -1 = Bad, 0 = Satisfactory, 1 = Good, 2 = Very good)

Figure G.8.21 shows that in Thecentre:mk 63 % of shop assistants interviewed consider the environmental conditions of their shops good for working, while 18 % of them just satisfactory. Instead, in Lakeside Shopping Centre 41 % of shop assistants interviewed consider the environmental conditions of the shops good for working and another 41 % just satisfactory. In Thecentre:mk nobody rates the environmental conditions of the shops very bad but in Lakeside Shopping Centre 3 % of interviewees does.

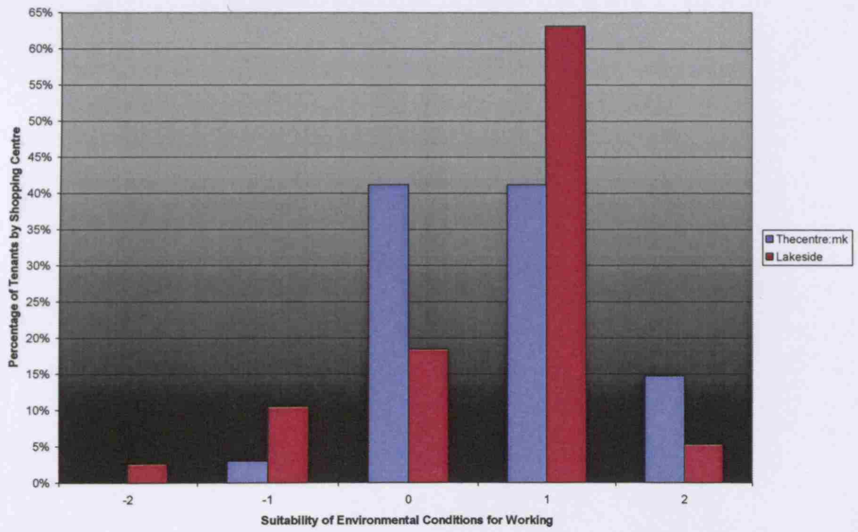

Figure G.8.21. Comparison of the suitability of the environmental conditions for working in the shops surveyed.

(Scale: -2 = Very bad, -1 = Bad, 0 = Satisfactory, 1 = Good, 2 = Very good)